International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

ICES COOPERATIVE RESEARCH REPORT

RAPPORT DES RECHERCHES COLLECTIVES

NO. 304 SPECIAL ISSUE

AUGUST 2010

ICES Report on Ocean Climate 2009

Prepared by the Working Group on Oceanic Hydrography

Cover image and above.
The west coast of Scotland from FRV Alba na Mara. Image courtesy of Marine Scotland, Aberdeen UK.

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:
Hughes, S. L., Holliday, N. P., and Beszczynska-Möller, A. (Eds). 2010. ICES Report on Ocean Climate 2009. ICES Cooperative Research Report No. 304. 67 pp.

Series Editor: Emory D. Anderson

ISBN: 978-87-7482-083-3
ISSN: 1017-6195

TABLE OF CONTENTS

1. INTRODUCTION

The North Atlantic region is unusual in having a relatively large number of locations at which oceanographic data have been collected repeatedly for many years or decades; the longest records go back more than a century. In this report, we provide the very latest information from the ICES Area of the North Atlantic and Nordic Seas, where the ocean is currently measured regularly. We describe the status of sea temperature and salinity during 2009, as well as the observed trends over the past decade or longer. In the first part of the report, we draw together the information from the longest time-series in order to give the best possible overview of changes in the ICES Area. Throughout the report, additional complementary datasets are provided, such as sea level pressure, air temperature, and ice cover.

The main focus of the annual ICES Report on Ocean Climate is the observed variability in the upper ocean (the upper 1000 m), and the introductory section includes gridded fields constructed by optimal analysis of the Argo float data distributed by the Coriolis data centre in France. Later in the report, a short section summarizes the variability of the intermediate and deep waters of the North Atlantic.

The data presented here represent an accumulation of knowledge collected by many individuals and institutions through decades of observations. It would be impossible to list them all, but at the end of the report, we provide a list of contacts for each dataset, including e-mail addresses for the individuals who provided the information, and the data centres at which the full archives of data are held.

More detailed analysis of the datasets that form the time-series presented in this report can be found in the annual meeting reports of the ICES Working Group on Oceanic Hydrography at http://www.ices.dk/iceswork/wgdetail.asp?wg=WGOH.

1.1 Highlights of 2009

The upper layers of the northern North Atlantic and the Nordic seas were warm and saline in 2009 compared with the long-term average.

A strong, cold anomaly developed in the surface of the central North Atlantic during summer.

Warming and salinification of deep waters continues.

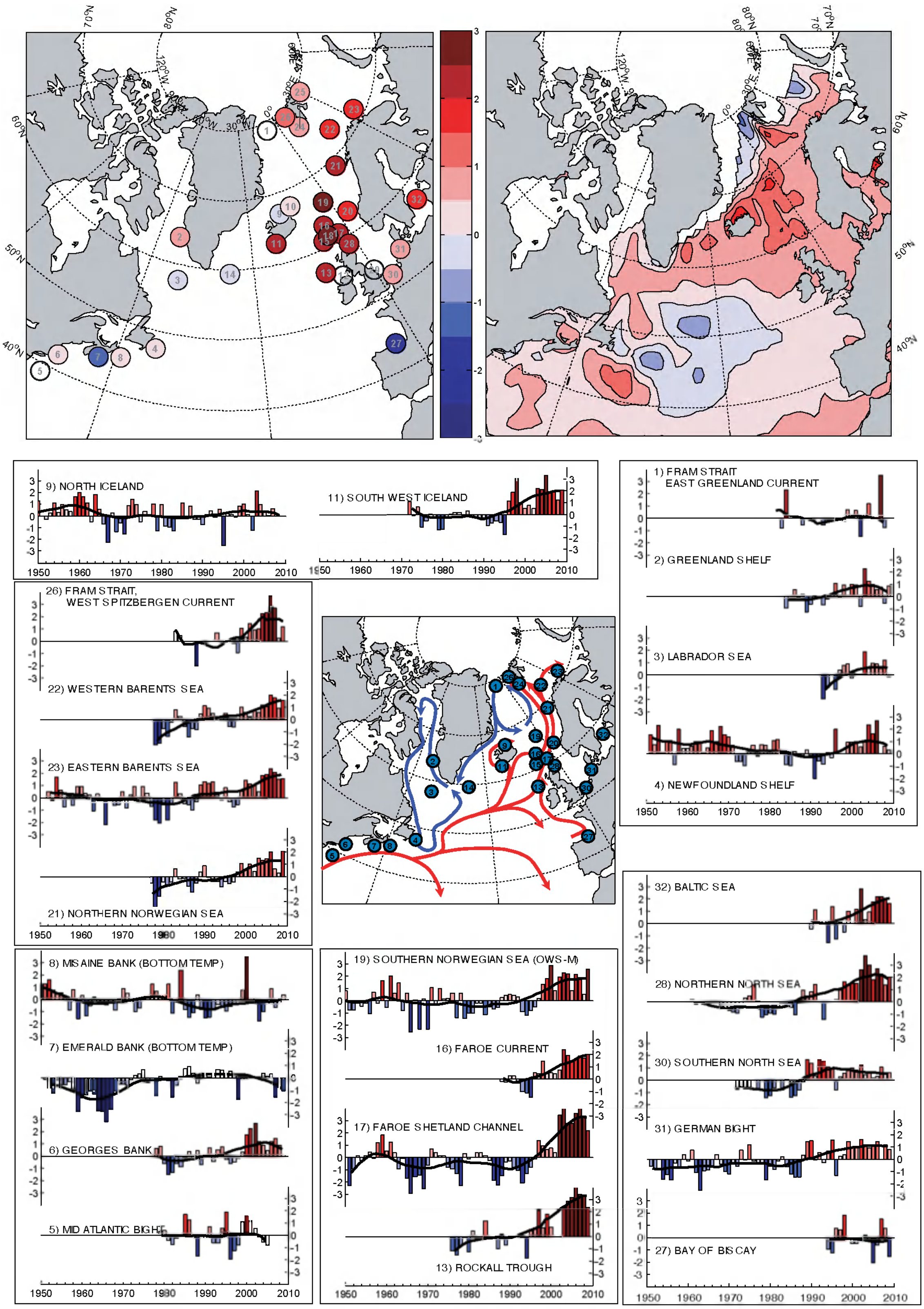
1.2 The North Atlantic atmosphere in winter 2008/2009

Surface air temperatures in the central North Atlantic and the Norwegian Sea were near normal, but were >1°C higher than average in the Labrador, Barents, and Greenland seas.

Mean winds were weaker than normal across the eastern North Atlantic, southern Labrador Sea, Northwestern European continental shelf, and Baltic, but stronger than normal east of Newfoundland and east of the Azores.

The NAO index in winter 2008/2009 was weakly negative.

NORTH ATLANTIC UPPER OCEAN TEMPERATURE: OVERVIEW



4/5

Figure 1.
Upper ocean temperature anomalies at selected locations across the North Atlantic. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations above normal). Upper panels: maps of conditions in 2009; (left) data from in situ *observations; (right) 2009 anomalies calculated from OISST.v2 data (see Figure 3). Lower panels: time-series of normalized anomalies at each of the selected stations. Colour intervals 0.5°C; reds = positive/warm; blues = negative/cool. See Figure 13 for a map supplying more details about the locations in this figure.*

NORTH ATLANTIC UPPER OCEAN SALINITY: OVERVIEW

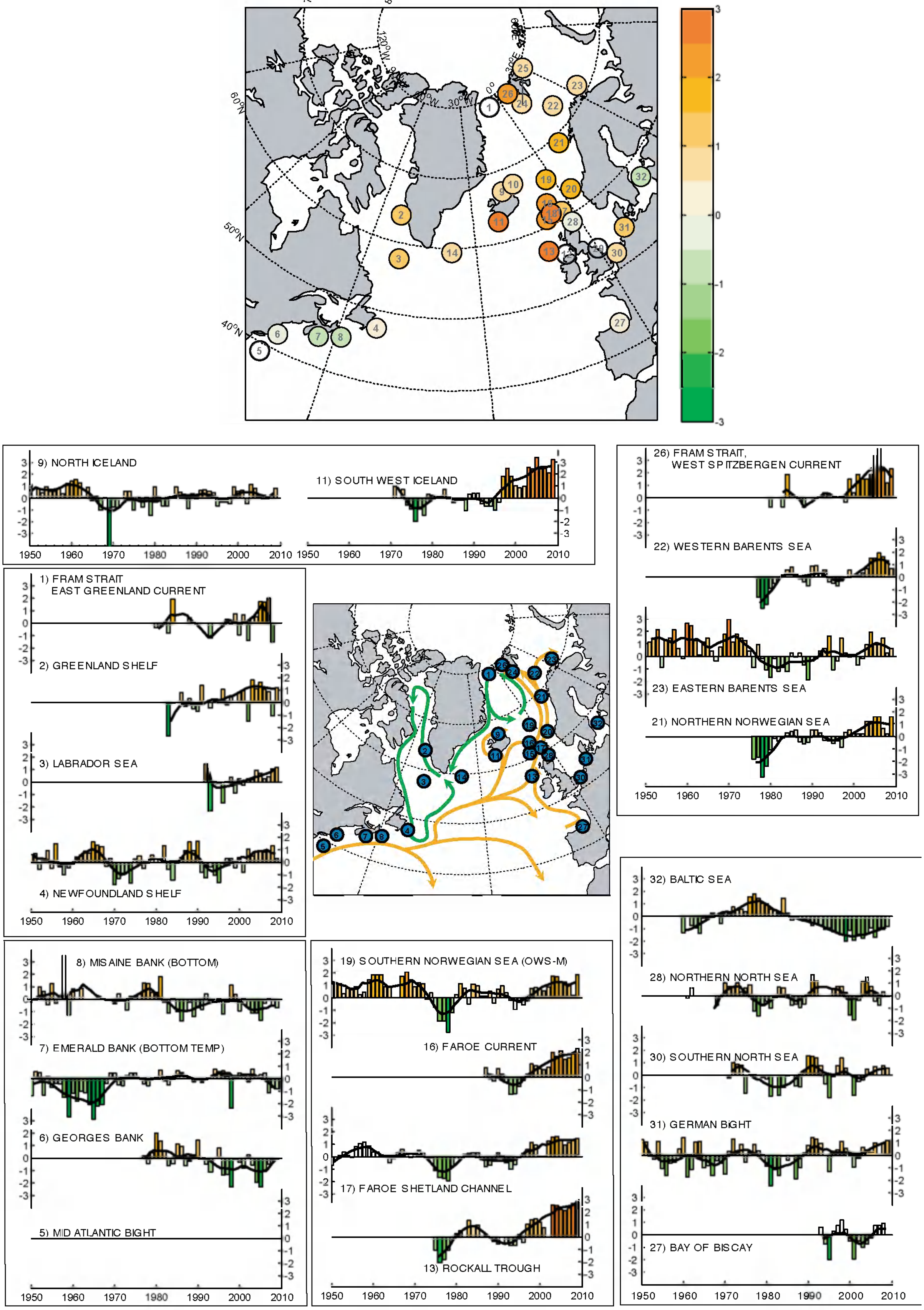


Figure 2.
Upper ocean salinity anomalies at selected locations across the North Atlantic. The anomalies are calculated relative to a long-term mean and normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations above normal). Upper panel: map of conditions in 2009. Lower panels: time-series of normalized anomalies at each of the selected stations. Colour intervals 0.5; oranges = positive/saline; greens = negative/fresh. See Figure 13 for a map supplying more details about the locations in this figure.

2. SUMMARY OF UPPER OCEAN CONDITIONS IN 2009

In this section, we summarize the conditions in the upper layers of the North Atlantic during 2009, using data from: (i) a selected set of sustained observations, (ii) gridded sea surface temperature (SST) data, and (iii) gridded vertical profiles of temperature and salinity from Argo floats.

2.1 *In situ* stations and sections

Where *in situ* section and station data are presented in the summary tables and figures, normalized anomalies have been demonstrated to allow better comparison of trends in the data from different regions (Figures 1–3; Tables 1 and 2).The anomalies have been normalized by dividing the values by the standard deviation of the data during 1971–2000. A value of +2 thus represents data (temperature or salinity) at 2 standard deviations higher than normal.

"SUSTAINED OBSERVATIONS" OR "TIME-SERIES" ARE REGULAR MEASUREMENTS OF OCEAN TEMPERATURE AND SALINITY MADE OVER A LONG PERIOD (10–100 YEARS). MOST MEASUREMENTS ARE MADE 1–4 TIMES A YEAR, BUT SOME ARE MADE MORE FREQUENTLY.

"ANOMALIES" ARE THE MATHEMATICAL DIFFERENCES BETWEEN EACH INDIVIDUAL MEASUREMENT AND THE AVERAGE VALUES OF TEMPERATURE, SALINITY, OR OTHER VARIABLES AT EACH LOCATION. POSITIVE ANOMALIES IN TEMPERATURE AND SALINITY MEAN WARM OR SALINE CONDITIONS; NEGATIVE ANOMALIES MEAN COOL OR FRESH CONDITIONS.

THE "SEASONAL CYCLE" DESCRIBES THE SHORT-TERM CHANGES AT THE SURFACE OF THE OCEAN BROUGHT ABOUT BY THE PASSING OF THE SEASONS; THE OCEAN SURFACE IS COLD IN WINTER AND WARMS THROUGH SPRING AND SUMMER. THE TEMPERATURE AND SALINITY CHANGES CAUSED BY THE SEASONAL CYCLE ARE USUALLY MUCH GREATER THAN THE PROLONGED YEAR-TO-YEAR CHANGES WE DESCRIBE HERE.

Aanderaa Seaguard ready for deployment. Image courtesy of Marine Scotland, Aberdeen UK.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1 (12)	0.06	0.60	-1.52	0.32	1.22	0.04	0.04	3.50	-0.75	
2 (1)	1.02	0.93	-0.80	2.27	1.26	0.99	0.56	0.76	-0.55	0.91
3 (2b)	-0.23	0.09	0.06	1.86	0.49	0.96	0.88	0.50	1.19	-0.16
4 (2)	0.94	1.03	0.56	0.97	2.41	1.62	2.68	0.01	0.62	0.29
5 (2c)	1.59	1.20	0.54	-0.13	-0.56	-0.83				
6 (2c)	1.79	2.24	2.72	1.21	0.86	0.45	1.17	1.48	0.89	0.11
7 (2)	0.22	0.04	0.09	0.07	0.35	0.10	0.33	-1.55	-0.73	-1.06
8 (2)	3.55	-0.31	0.14	-1.77	-1.01	-0.02	0.88	-0.62	-0.31	0.38
9 (3)	1.02	0.07	-1.19	2.11	0.94	0.44	0.05	0.61	-0.02	-0.02
10 (3)	-0.44	-0.49	-1.04	1.54	0.39	-0.16	0.14	-0.44	0.38	0.27
11 (3)	0.52	0.73	0.47	2.22	2.15	3.34	1.95	1.89	1.19	2.07
12 (4b)	1.38	0.50	1.38	1.82	2.69	2.48	2.26	3.13		
13 (5)	0.74	0.14		2.34	2.88	3.24	4.38	3.48	3.34	2.38
14 (5b)	0.26	1.24	1.04	1.11	2.72	1.58	1.22	2.01	0.33	-0.07
15 (6)	0.34	0.86	0.89	2.75	2.43	1.53	2.58	2.34	2.62	2.02
16 (6)	0.49	0.45	0.74	2.37	1.96	1.50	1.59	1.92	1.71	2.00
17 (7)	0.73	0.40	3.47	4.33	2.80	2.80	3.60	4.40	3.40	2.20
18 (7)	1.20	1.64	2.84	3.24	2.84	2.36	2.64	2.92	3.00	3.52
19 (10)	2.88	0.80	1.94	2.27	2.20	0.85	2.14	1.90	0.49	2.57
20 (10)	0.88	0.67	2.08	1.70	0.78	0.55	1.49	2.11	0.39	1.93
21 (10)	0.54	1.02	0.46	1.49	1.35	1.46	2.01	0.64	0.32	2.05
22 (11)	0.59	0.27	0.77	0.58	1.21	1.10	1.99	1.79	0.96	1.55
23 (11)	1.47	1.16	1.04	0.48	1.80	1.86	2.39	2.10	1.49	1.59
24 (12)	0.12	0.13	-0.08	-0.68	0.50	1.10	2.13	1.14	1.08	0.67
25 (10)	0.14	-0.20	0.35	-0.07	0.58	1.32	1.50	0.78	0.35	0.62
26 (12)	0.34	1.45	0.95	1.03	2.29	2.33	3.71	2.74	0.24	1.18
27 (4)	-0.47	-0.48	-0.37	0.21	-0.31	-2.10	-0.61	1.50	0.76	-1.57
28 (89)	1.53	1.53	2.65	3.79	3.00	1.85	2.71	2.29	1.38	2.00
29 (89)	0.60	0.49	0.69	0.84	0.68	0.17				
30 (89)	0.99	0.82	1.25	0.43	0.64	0.18	0.29	1.04	0.48	0.62
31 (89)	0.97	0.95	1.66	1.17	0.95	1.15	1.43		1.21	0.82
32 (9b)		1.20	2.84	0.29	0.98	1.76	2.23	2.23	2.06	1.64

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1 (12)	-0.94	0.69	-1.40	0.42	0.51	1.78	1.69	2.01	-1.54	
2 (1)	0.80	1.02	-1.54	1.85	1.15	1.62	1.10	0.90	-1.06	1.20
3 (2b)	0.25	-0.24	0.27	0.17	0.92	0.71	0.24	0.46	1.04	1.17
4 (2)	0.38	-0.81	1.08	0.50	0.88	0.92	0.85	0.92	1.35	0.31
5 (2c)										
6 (2c)	-0.34	-0.83	0.25	-0.59	-1.96	-2.30	-1.08	-0.48	-0.13	-0.13
7 (2)	0.44	0.25	-0.22	0.74	0.17	0.34	0.44	-1.12	-0.67	-0.81
8 (2)	-0.97	0.12	-0.70	-1.15	-1.16	-1.73	-0.29	0.06	-0.50	-0.69
9 (3)	0.56	0.61	-0.48	1.14	0.81	0.02	-0.09	-0.09	-0.04	0.82
10 (3)	0.59	0.34	-0.12	0.29	0.35	0.18	0.70	0.69	0.75	0.55
11 (3)	0.99	0.83	0.97	2.54	2.37	3.40	2.37	2.46	2.08	3.17
12 (4b)										
13 (5)	1.17	0.74		2.57	2.52	2.19	2.13	2.34	2.71	2.82
14 (5b)	0.10	0.70	1.37	0.54	2.45	1.84	1.53	1.72	0.76	0.89
15 (6)	0.70	0.54	0.57	2.16	2.37	1.92	1.41	1.62	2.53	2.20
16 (6)	0.68	0.63	0.83	2.02	1.73	2.15	1.46	1.58	1.92	2.32
17 (7)	0.09	0.09	1.27	1.59	1.64	1.34	0.93	1.14	1.41	1.46
18 (7)	0.97	1.23	1.86	2.20	2.09	2.06	1.89	1.37	1.89	2.80
19 (10)	0.77	0.55	0.89	1.73	1.71	1.24	1.26	1.11	0.22	1.89
20 (10)	0.41	0.06	0.78	0.96	0.99	0.77	0.75	0.95	0.60	1.77
21 (10)	0.18	0.20	0.18	1.17	1.20	1.60	1.57	0.63	0.20	1.60
22 (11)	0.16	0.06	0.33	0.71	1.52	1.49	1.96	1.61	1.34	0.72
23 (11)	0.12	-0.72	-0.22	0.95	1.95	0.95	0.95	1.45	0.28	0.62
24 (12)	-0.33	0.12	0.16	-0.19	0.49	1.40	1.88	1.54	0.67	0.93
25 (10)	0.06	-0.22	0.40	0.14	0.74	1.48	1.70	1.30	0.90	0.80
26 (12)	0.38	1.89	1.51	1.51	1.89	3.40	4.15	2.23	1.17	2.30
27 (4)	-0.53	-1.94	-0.49	-1.02	-0.77	-0.23	0.76	0.77	0.94	0.02
28 (89)	-1.56	-1.93	-0.40	1.14	1.50	0.79	-0.43	-0.74	0.33	-0.07
29 (89)										
30 (89)	0.08	-1.65	-0.50	-0.39	0.52	0.18	0.72	-0.03	0.73	0.58
31 (89)	0.04	-0.95	-0.27	0.60	0.44	0.27	1.01		0.94	1.20
32 (9b)	-1.12	-1.98	-1.48	-1.79	-1.40	-0.98	-1.70	-0.94	-1.07	-0.81

Tables 1 and 2.

Changes in temperature (Table 1, top) and salinity (Table 2, bottom) at selected stations in the North Atlantic region during the last decade: 2000–2009. The index numbers on the left can be used to cross-reference each point with information in Figures 1 and 2 and in Table 3. The numbers in brackets refer to detailed area descriptions featured later in the report. Unless specified, these are upper layer anomalies. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates that the data (temperature or salinity) for that year were 2 standard deviations above normal). Blank boxes indicate that data were unavailable for a particular year at the time of publication. Note that no salinity data are available for stations 5, 12, and 29. Colour intervals 0.5; red = warm; blue = cold; orange = saline; green = fresh.

2.2 Sea surface temperature

Sea surface temperatures across the entire North Atlantic have also been obtained from a combined satellite and *in situ* gridded dataset. Figure 3 shows the seasonal SST anomalies for 2009, extracted from the Optimum Interpolation SST dataset (OISST.v2) provided by the NOAA-CIRES Climate Diagnostics Center in the USA. In high latitudes, where *in situ* data are sparse and satellite data are hindered by cloud cover, the data may be less reliable. Regions with ice cover for >50% of the averaging period appear blank.

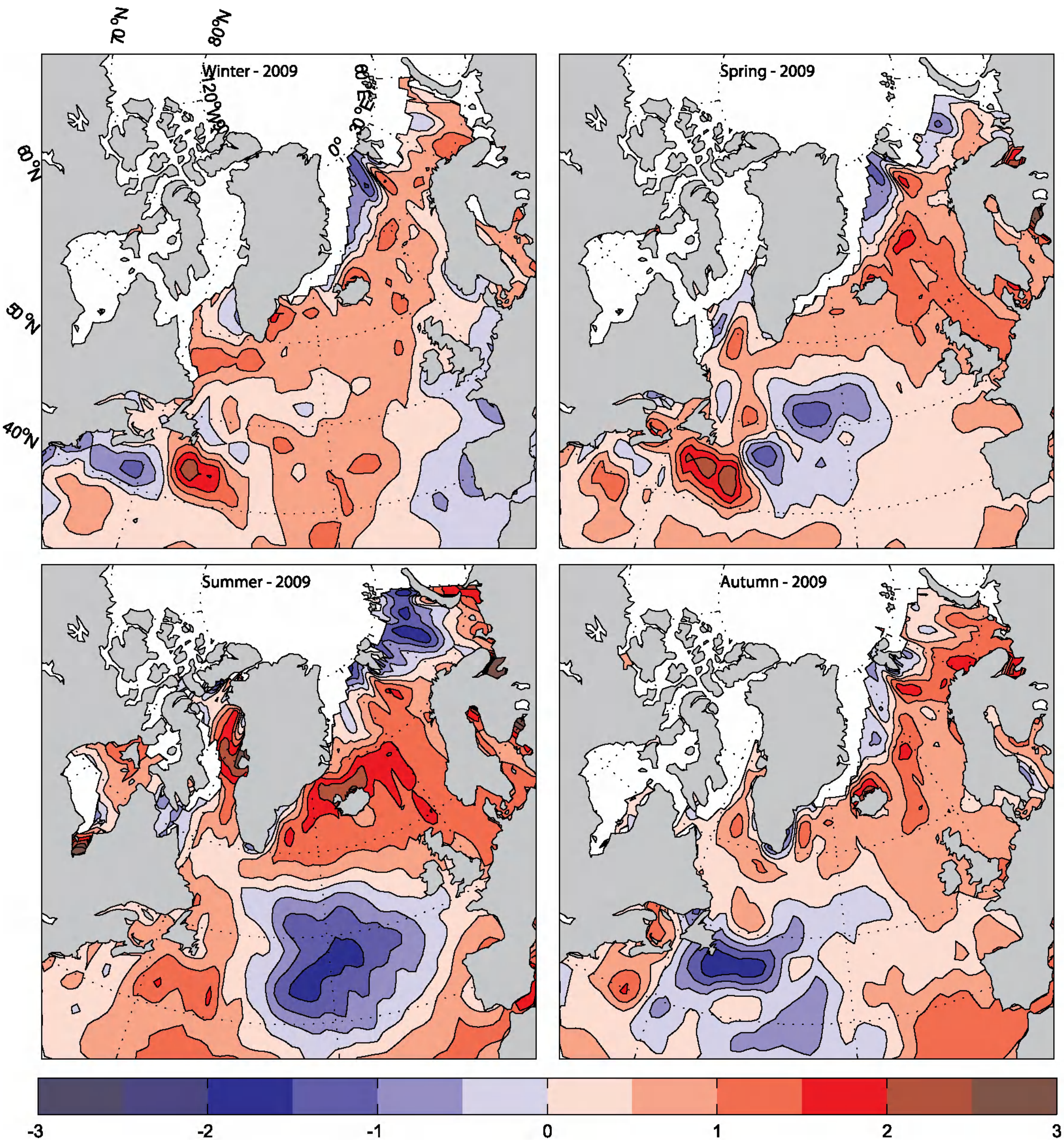


Figure 3.
Maps of seasonal sea surface temperature anomalies (°C) over the North Atlantic for 2009 from the NOAA Optimum Interpolation SSTv2 dataset provided by the NOAA-CIRES Climate Diagnostics Center, USA. The colour-coded temperature scale is the same in all panels. The anomaly is calculated with respect to normal conditions for 1971–2000. The data are produced on a 1-degree grid from a combination of satellite and in situ *temperature data. Regions with ice cover for >50% of the averaging period are left blank.*

Table 3. Details of the datasets included in Figures 1 and 2 and in Tables 1 and 2. Blank boxes indicate that no information was available for the area at the time of publication. T = temperature; S = salinity. Some data are calculated from an average of more than one station; in such cases, the latitudes and longitudes presented here represent a nominal midpoint along that section.

Index	Description	Area	Measurement depth	Long-term average	Lat	Lon	Mean T, °C	S.d. T, °C	Mean S	S.d. S
1	Fram Strait – East Greenland Current Section Average 3°W to shelf edge	12	50–500 m	1980–2000	78.83	-8.00	0.58	0.39	34.67	0.11
2	Station 4 – Fylla Station – Greenland Shelf	1	0–200 m	1971–2000	63.88	-53.37	3.74	1.03	33.88	0.30
3	Area 2b – west-central Labrador Sea - Section AR7W	2b	0–150 m	1990–2009	57.73	-51.07	3.73	0.45	34.71	0.07
4	Station 27 – Newfoundland Shelf (temperature) – Canada	2	0–175 m	1971–2000	47.55	-52.59	0.27	0.34	31.63	0.26
5	Oleander Section (120–400 km) – Mid-Atlantic Bight, USA	2c	Surface	1978–2000	39.00	-71.50		0.86		
6	Northwest Georges Bank – Mid-Atlantic Bight, USA	2c	1–30 m	1977–2000	42.00	-70.00	9.71	1.61	32.64	0.23
7	Emerald Basin – Central Scotian Shelf – Canada	2	Near Bottom	1971–2000	44.00	-63.00		1.20		0.23
8	Misaine Bank – Northeastern Scotian Shelf – Canada	2	Near Bottom	1971–2000	45.00	-59.00		0.65		0.16
9	Siglunes Station 2–4 – North Iceland – Irminger Current	3	50–150 m	1971–2000	67.00	-18.00	3.34	1.09	34.82	0.19
10	Langanes Station 2–6 – Northeast Iceland – East Icelandic Current	3	0–50 m	1971–2000	67.50	-13.50	1.24	0.95	34.70	0.14
11	Selvogsbanki Station 5 – Southwest Iceland – Irminger Current	3	0–200 m	1971–2000	63.00	-22.00	7.64	0.37	35.15	0.04
12	Malin Head Weather Station	4b	Surface	1971–2000	55.37	-7.34	10.57	0.46		
13	Ellett Line – Rockall Trough – UK (section average)	5	0–800 m	1975–2000	56.75	-11.00	9.21	0.22	35.33	0.03
14	Central Irminger Sea – Subpolar Mode Water	5b	200–400 m	1991–2005	59.40	-36.80	3.99	0.55	34.88	0.03
15	Faroe Bank Channel – West Faroe Islands	6	Layer between 100 and 300 m depth	1988–2000	61.00	-8.00	8.23	0.32	35.24	0.04
16	Faroe Current – North Faroe Islands (Modified North Atlantic Water)	6	Upper-layer, high-salinity core	1988–2000	63.00	-6.00	7.92	0.37	35.22	0.04
17	Faroe – Shetland Channel – Shetland Shelf (North Atlantic Water)	7	Upper-layer, high-salinity core	1971–2000	61.00	-3.00	9.57	0.15	35.36	0.04
18	Faroe – Shetland Channel – Faroe Shelf (Modified North Atlantic Water)	7	Upper-layer, high-salinity core	1971–2000	61.50	-6.00	7.85	0.25	35.22	0.04
19	Ocean Weather Station "M" – 50 m	10	50 m	1971–2000	66.00	-2.00	7.49	0.34	35.15	0.05
20	Southern Norwegian Sea – Svinøy Section – Atlantic Water	10	50–200 m	1977–2000	63.00	3.00	7.99	0.39	35.23	0.05
21	Central Norwegian Sea – Gimsøy Section – Atlantic Water	10	50–200 m	1977–2000	69.00	10.00	6.81	0.39	35.15	0.04
22	Fugløya – Bear Island Section – western Barents Sea – Atlantic Inflow	11	50–200 m	1977–2006	73.00	20.00	5.35	0.52	35.06	0.05
23	Kola Section – eastern Barents Sea	11	0–200 m	1971–2000	71.50	33.30	3.92	0.49	34.76	0.06
24	Greenland Sea Section – west of Spitsbergen 76.5°N	12	200 m	1996–2008	76.50	10.50	3.08	0.66	35.05	0.04
25	Northern Norwegian Sea – Sørkapp Section – Atlantic Water	10	50–200 m	1977–2000	76.33	10.00	3.80	0.71	35.05	0.05
26	Fram Strait – West Spitsbergen Current – Section average 5°E to shelf edge	12	50–500 m	1980–2000	78.83	8.00	2.60	0.58	34.99	0.03
27	Santander Station 6 (shelf break) – Bay of Biscay – Spain	4	5–200 m	1993–2000	43.70	-3.78	12.72	0.18	35.61	0.05
28	Fair Isle Current Water (waters entering North Sea from Atlantic)	8 & 9	0–100 m	1971–2000	59.00	-2.00	9.71	0.34	34.84	0.07
29	UK Coastal Waters – Southern Bight – North Sea	8 & 9	Surface	1971–2000	54.00	0.00				
30	Section average – Felixstowe – Rotterdam – 52°N	8 & 9	Surface	1971–2000	52.00	3.00	12.24	0.81	34.65	0.21
31	Helgoland Roads – coastal waters – German Bight – North Sea	8 & 9	Surface	1971–2000	54.19	7.90	10.10	0.72	32.11	0.54
32	Baltic Proper – east of Gotland – Baltic Sea	9b	Surface	1971–2000 (S) 1990–2000 (T)	57.50	19.50	8.57	0.86	7.35	0.24

2.3 Argo gridded temperature and salinity fields

In this section, we present summaries of recent conditions in the North Atlantic, as described by the growing data resource provided by Argo float temperature and salinity profiles. The gridded fields were generated by ISAS (*In Situ* Analysis System), a tool developed and maintained at the LPO (Laboratoire de Physique des Océans) within the CREST-Argo project (http://wwz.ifremer.fr/lpo/observation/crest_argo). The latest version, ISAS_V5.2, was used to produce monthly gridded fields of temperature and salinity at depth levels of 0–2000 m. The datasets used are the standard files prepared by Coriolis for operational users and contain mainly Argo profiles, with some additional CTD profiles, and buoy and mooring data.

Figure 4 shows the 2009 seasonal mean fields of temperature and salinity at 10 m depth depicted as anomalies from the reference climatology (World Ocean Atlas, WOA-05). In Figure 5, the 2009 annual anomaly fields of temperature and salinity are presented at four depths: 10, 300, 1000, and 1600 m. Anomalies for 2004–2009 at two selected depths, 10 and 1600 m, are given in Figures 6 and 7.

Finally, in Figure 8, the winter (February) mixed-layer depth for 2004–2009 is shown. Note that the mixed-layer depth (z) is defined as the depth where the temperature has decreased by 0.5°C from the temperature measured at 10 m depth ($T(z) < T(10\ m) - 0.5$). This criterion is not suitable for areas where effects of salinity are important (ice melting) or where the basic stratification is weak. Therefore, results in the Labrador Sea, around Greenland, and in the Gulf of Lion are not significant.

Figure 8 illustrates the regional winter mixed-layer development by demonstrating the maximum depth of the mixed layer in February 2004–2009. In 2008, the winter mixed layer was generally deep in the eastern regions, including the Bay of Biscay, and exceptionally deep in the area of Madeira mode water. In contrast, it was shallower in 2009 than in 2008 in the Labrador and Irminger seas.

On average, during 2009, northeast of a line between Cape Finisterre and south of Greenland, the North Atlantic was warmer than the climatology in the near-surface layer (10 m). The warm anomaly was more intense in the Greenland Sea, where there has been warming since 2004. The cold anomaly in summer in the centre of the basin dominates the annual mean and appears as the most striking feature of this year. A positive salinity anomaly has progressed along the western boundary from northeast of Greenland to west of the Labrador Sea and along the coast of North America. This saline anomaly replaced the fresh anomaly observed in the Labrador Sea in 2008, although a fresh anomaly is associated with the coldest areas (centre of the basin and Newfoundland Banks). The cold and fresh area is still visible at 300 m depth.

At greater depth (1000 and 1600 m), the Greenland Sea is warmer and also slightly more saline than the climatology in the western part (along Greenland). The Irminger and Labrador seas are warmer, especially at 1600 m, where this temperature anomaly is associated with more saline water. These features have been gradually developing since 2004. At 1000 m, the influence of the Mediterranean water (warm-saline anomaly) increases south of 48°N and decreases north of this latitude. At 1600 m, the influence of the Mediterranean water appears to be reduced. The tendency for a decrease in temperature and salinity is particularly obvious along the eastern boundary.

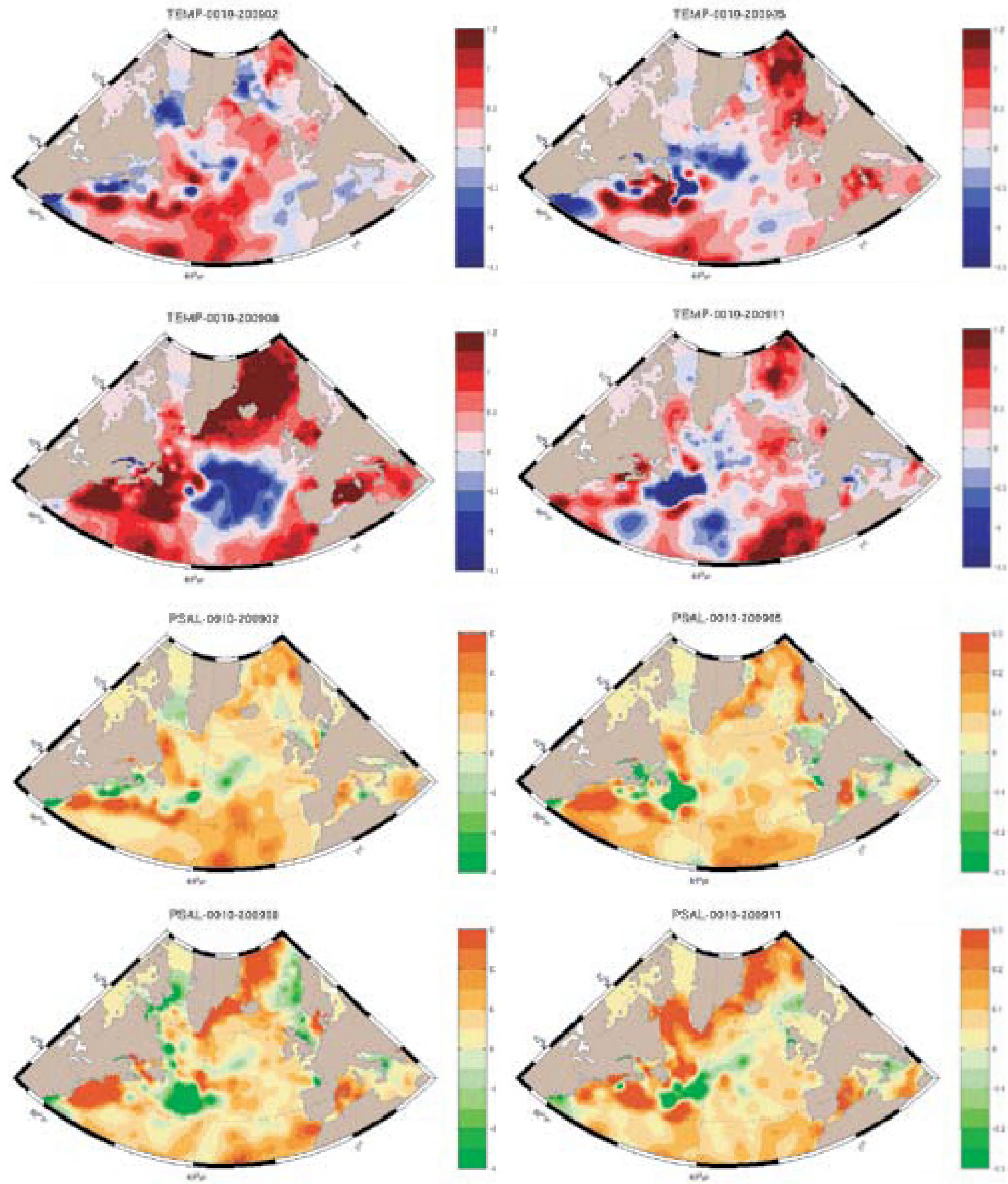


Figure 4.
Maps of 2009 seasonal temperature anomalies (upper) and salinity anomalies (lower) at 10 m depth in the North Atlantic from the ISAS monthly analysis of Argo data. The colour-coded temperature scale is the same in all panels. (Anomalies are the differences between the ISAS monthly mean values and the reference climatology, WOA-05.)

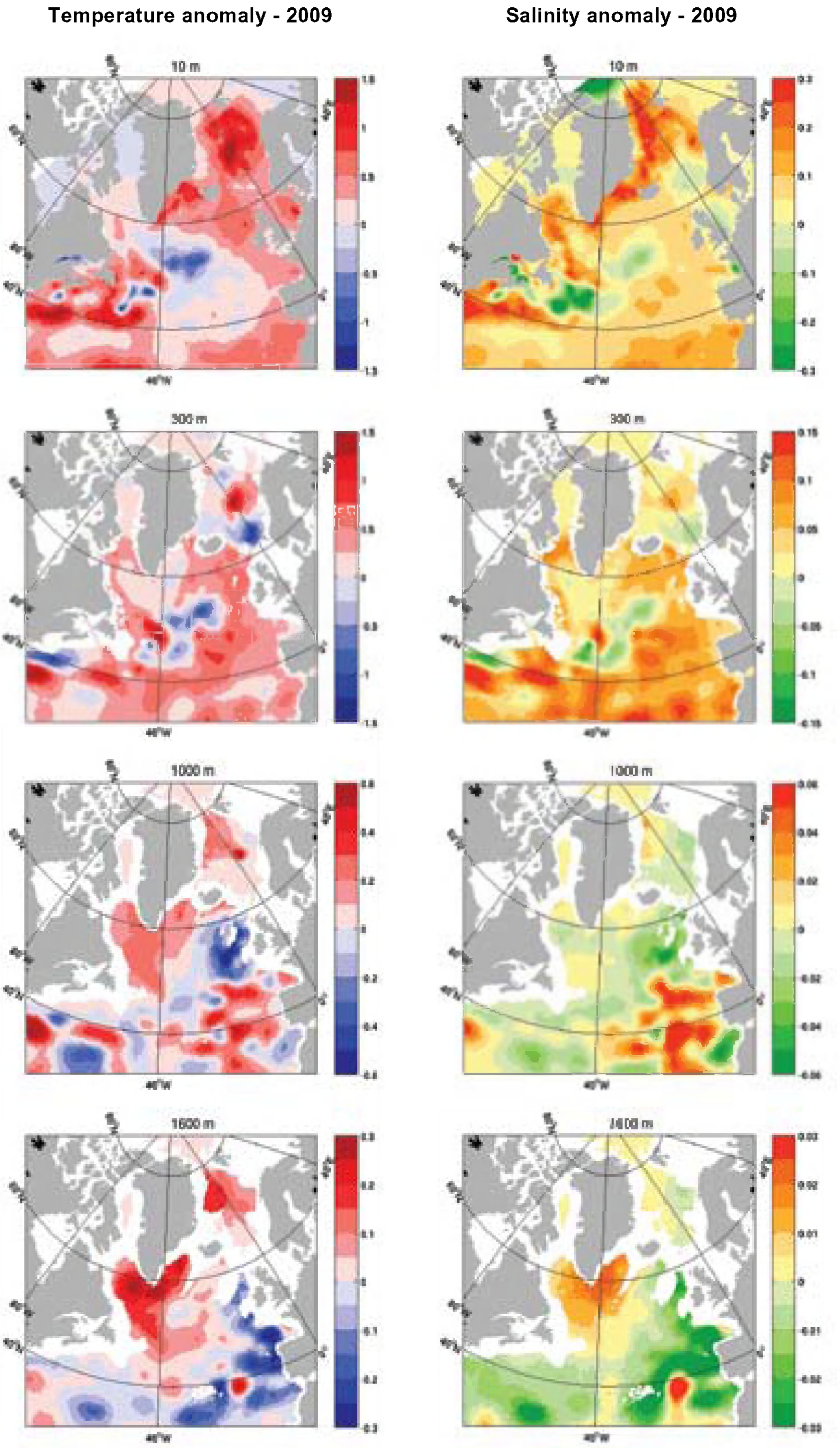


Figure 5.
Maps of 2009 annual temperature anomalies (left) and salinity anomalies (right) at 10, 300, 1000, and 1600 m. (Anomalies are the differences between the ISAS annual means and the reference climatology (WOA-05). Note the different scales for each map.) From the ISAS monthly analysis of Argo data.

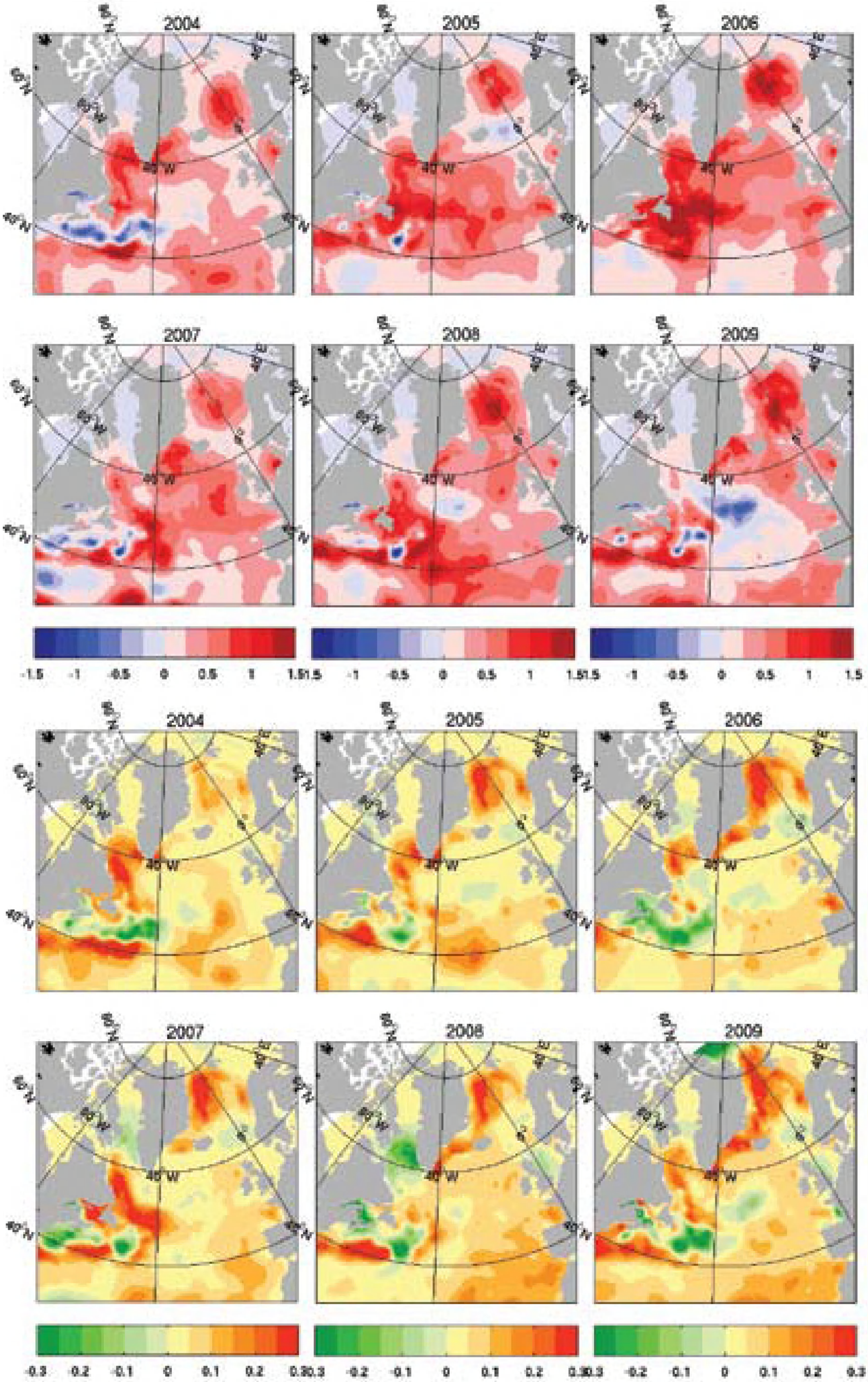


Figure 6.
Maps of annual temperature anomalies (upper) and salinity anomalies (lower) at 10 m for 2004–2009. From the ISAS monthly analysis of Argo data.

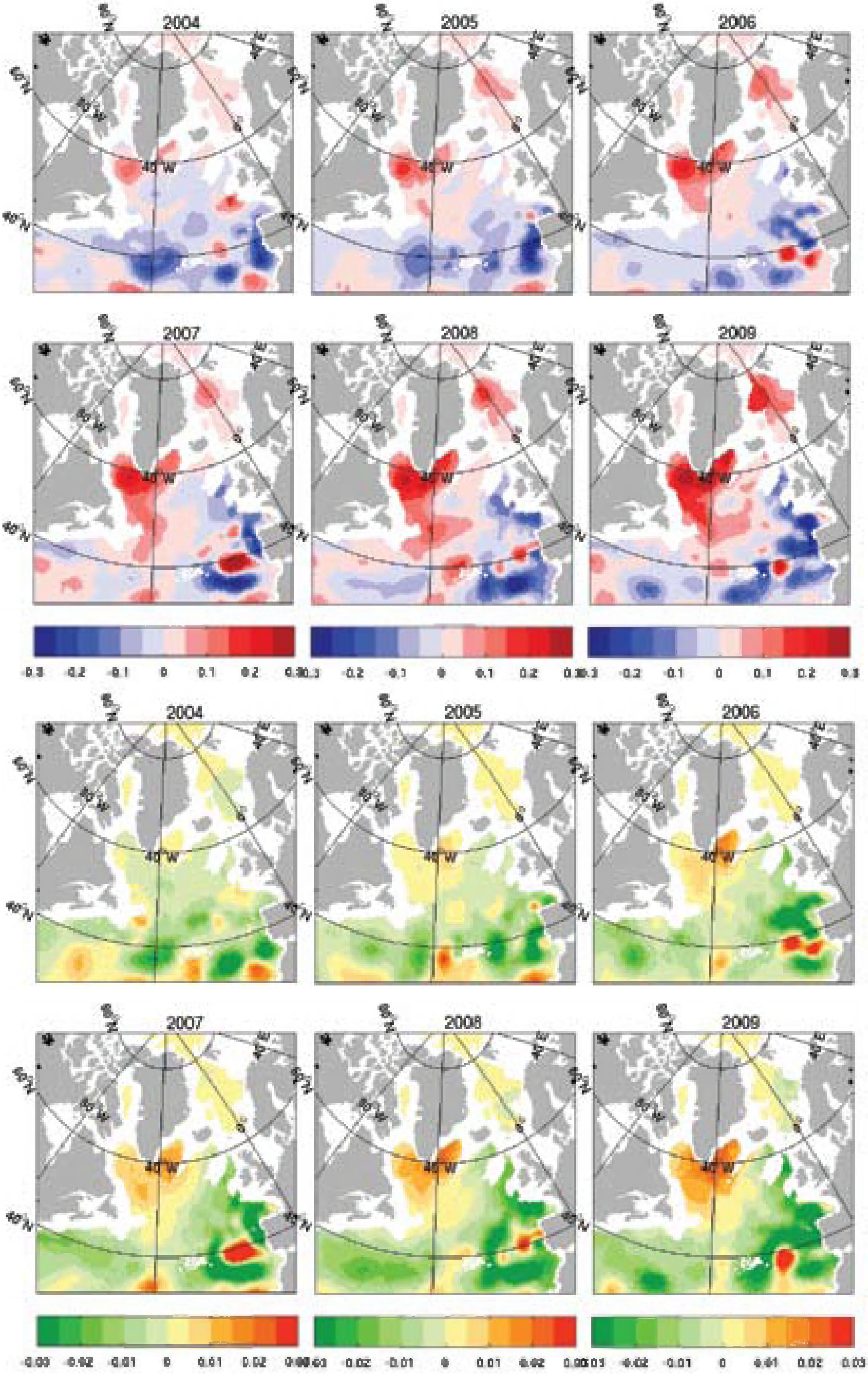


Figure 7.
Maps of annual temperature anomalies (upper) and salinity anomalies (lower) at 1600 m for 2004–2009. From the ISAS monthly analysis of Argo data.

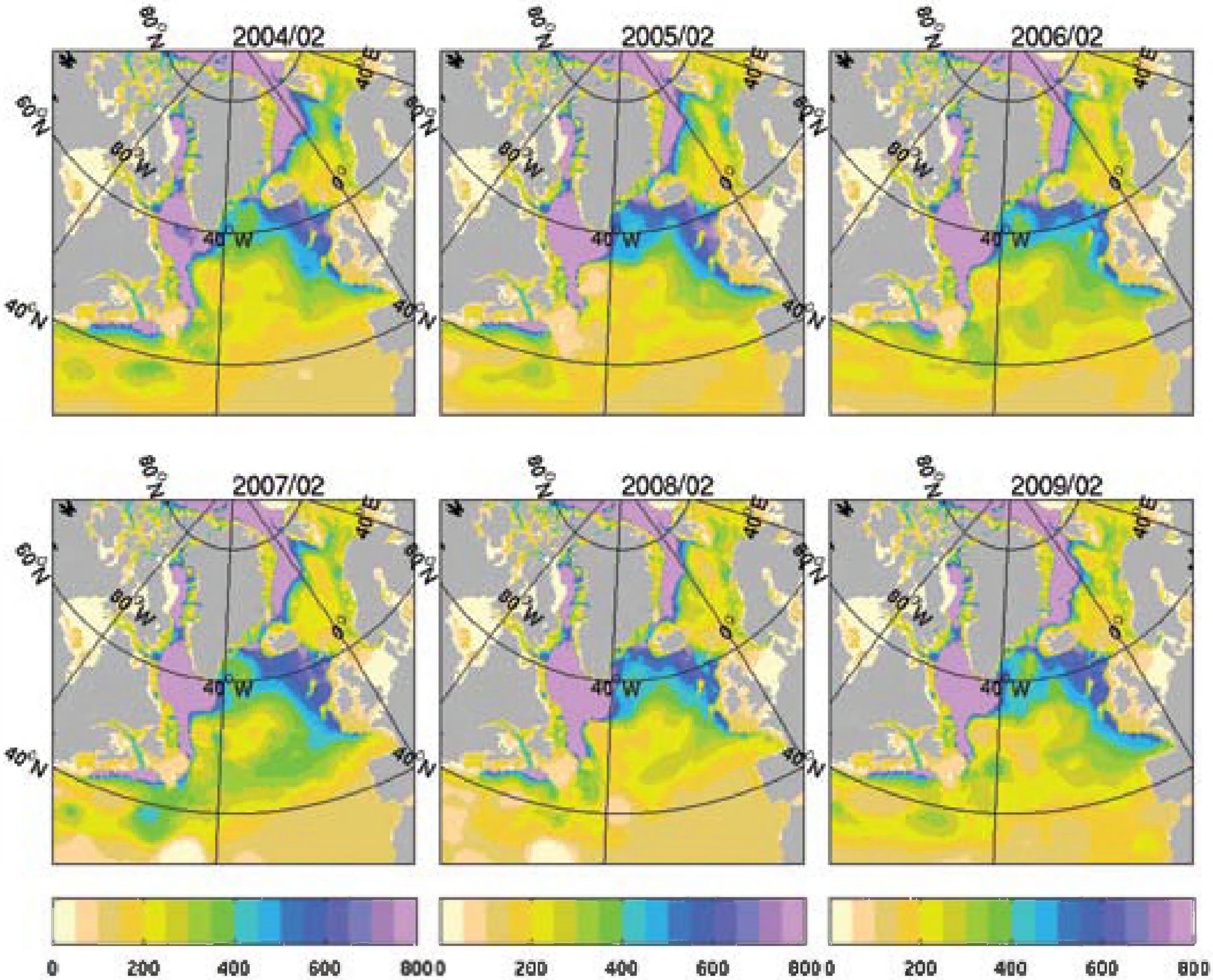


Figure 8.
Maps of North Atlantic winter (February) mixed-layer depths for 2004–2009. From ISAS monthly analysis of Argo data. Note that the mixed-layer depth is defined as the depth at which the temperature has decreased by more than 0.5°C from the temperature at 10 m depth. This criterion is not suitable for areas where effects of salinity are important (ice melting) or where the basic stratification is weak. Therefore, results in the Labrador Sea, around Greenland, and in the Gulf of Lion are not significant.

3. THE NORTH ATLANTIC ATMOSPHERE

3.1 Sea level pressure

The North Atlantic Oscillation (NAO) is a pattern of atmospheric variability that has a significant impact on oceanic conditions. It affects windspeed, precipitation, evaporation, and the exchange of heat between ocean and atmosphere, and its effects are most strongly felt in winter. The NAO index is a simple device used to describe the state of the NAO. It is a measure of the strength of the sea level air pressure gradient between Iceland and Lisbon, Portugal. When the NAO index is positive, there is a strengthening of the Icelandic low-pressure system and the Azores high-pressure system. This produces stronger mid-latitude westerly winds, with colder and drier conditions over the western North Atlantic and warmer and wetter conditions in the eastern North Atlantic. When the NAO index is negative, there is a reduced pressure gradient, and the effects tend to be reversed.

There are several slightly different versions of the NAO index calculated by climate scientists. The Hurrell winter (December/January/February/March (DJFM)) NAO index is most commonly used and is particularly relevant to the eastern North Atlantic. Following a long period of increase, from an extreme and persistent negative phase in the 1960s to a most extreme and persistent positive phase during the late 1980s and early 1990s, the Hurrell NAO index underwent a large and rapid decrease during winter 1995/1996. In winter 2008/2009, the NAO index was weakly negative (0.4; Figure 9).

Since then, the Hurrell NAO index has been fairly weak and a less useful descriptor of atmospheric conditions. However, two additional dominant atmospheric regimes have recently been recognized as useful descriptors: (i) the Atlantic Ridge mode, when a strong anticyclonic ridge develops off western Europe (similar to the East Atlantic pattern): and (ii) the Blocking regime, when the anticyclonic ridge develops over Scandinavia. The four regimes (positive NAO, negative NAO, Atlantic Ridge, and Blocking) have all been occurring at around the same frequency (20–30% of all winter days) since 1950. These modes of variability are revealed through cluster analysis of sea level pressure (SLP) rather than examining point-to-point SLP gradients.

THE OCEAN CAN RESPOND QUICKLY TO THE STATE OF THE NAO, PARTICULARLY IN WINTER, WHEN ATMOSPHERIC CONDITIONS AFFECT THE OCEAN SO INTENSELY THAT THE EFFECTS ARE FELT THROUGHOUT THE FOLLOWING YEAR. SOME REGIONS, SUCH AS THE NORTHWEST ATLANTIC AND THE NORTH SEA, ARE MORE RESPONSIVE TO THE NAO THAN OTHER REGIONS, SUCH AS THE ROCKALL TROUGH. HOWEVER, THE NAO IS NOT THE ONLY, OR EVEN THE MAIN, CONTROL ON OCEAN VARIABILITY. OVER THE ATLANTIC AS A WHOLE, THE NAO STILL ONLY ACCOUNTS FOR ONE-THIRD OF THE TOTAL VARIANCE IN WINTER SLP. THE CHAOTIC NATURE OF ATMOSPHERIC CIRCULATION MEANS THAT, EVEN DURING PERIODS OF STRONGLY POSITIVE OR NEGATIVE NAO WINTERS, THE ATMOSPHERIC CIRCULATION TYPICALLY EXHIBITS SIGNIFICANT LOCAL DEPARTURES FROM THE IDEALIZED NAO PATTERN.

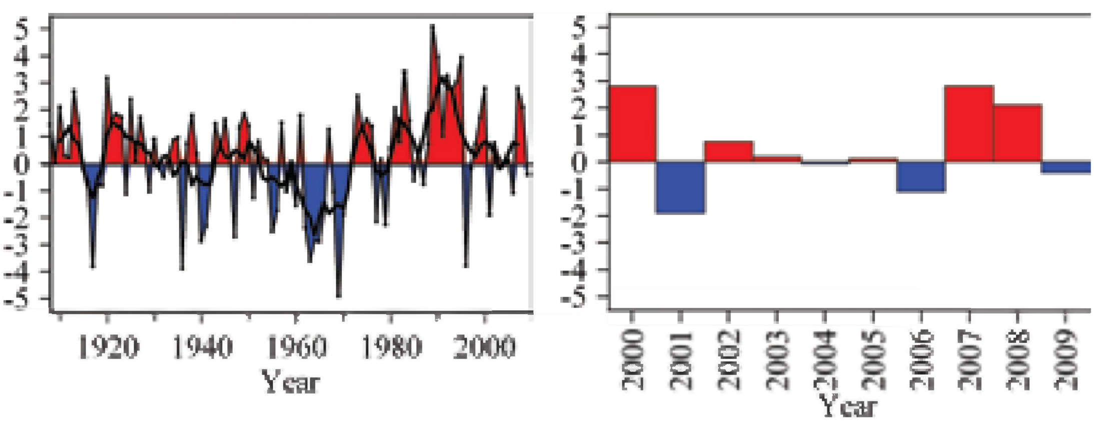


Figure 9.
The Hurrell winter (DJFM) NAO index for the last 100 years with a 2-year running mean applied (left panel) and for the current decade (right panel). Data source: http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html.

The NAO index is an indicator of the gradient of SLP, but maps can provide more information about the windfield. Ocean properties are particularly dominated by winter conditions, hence the inclusion of maps of SLP for winter (DJFM, Figure 10). The top panel of Figure 10 shows the winter SLP averaged over 30 years (1971–2000). The dominant features ("action centres") are the Iceland Low (the purple patch situated southwest of Iceland) and the Azores High (the orange patch west of Gibraltar).

The middle panel of Figure 10 shows the mean SLP for winter 2009 (December 2008, January–March 2009), and the bottom panel shows the 2009 winter SLP anomaly – the difference between the top and middle panels. In winter 2009, the Iceland Low was very close to the 1971–2000 average in both strength and position, with a slight deepening over the Labrador Sea. The Azores High was average in strength, but did not extend eastwards across Portugal and Spain, leading to the slightly negative value for the NAO index. The strength of the mean surface wind averaged over the 30-year period (1971–2000) is shown in the upper panel of Figure 11, and the lower panel shows the anomaly in winter 2009. These re-analyses demonstrate that the mean winds were weaker than normal across the eastern North Atlantic, southern Labrador Sea, Northwest European continental shelf, and Baltic, but stronger than normal east of Newfoundland and east of the Azores into the Mediterranean.

THE FIGURES SHOW CONTOURS OF CONSTANT SEA LEVEL PRESSURE (ISOBARS). THE GEOSTROPHIC (OR "GRADIENT") WIND BLOWS PARALLEL WITH THE ISOBARS, WITH LOWER PRESSURE TO THE LEFT. THE CLOSER THE ISOBARS, THE STRONGER THE WIND.

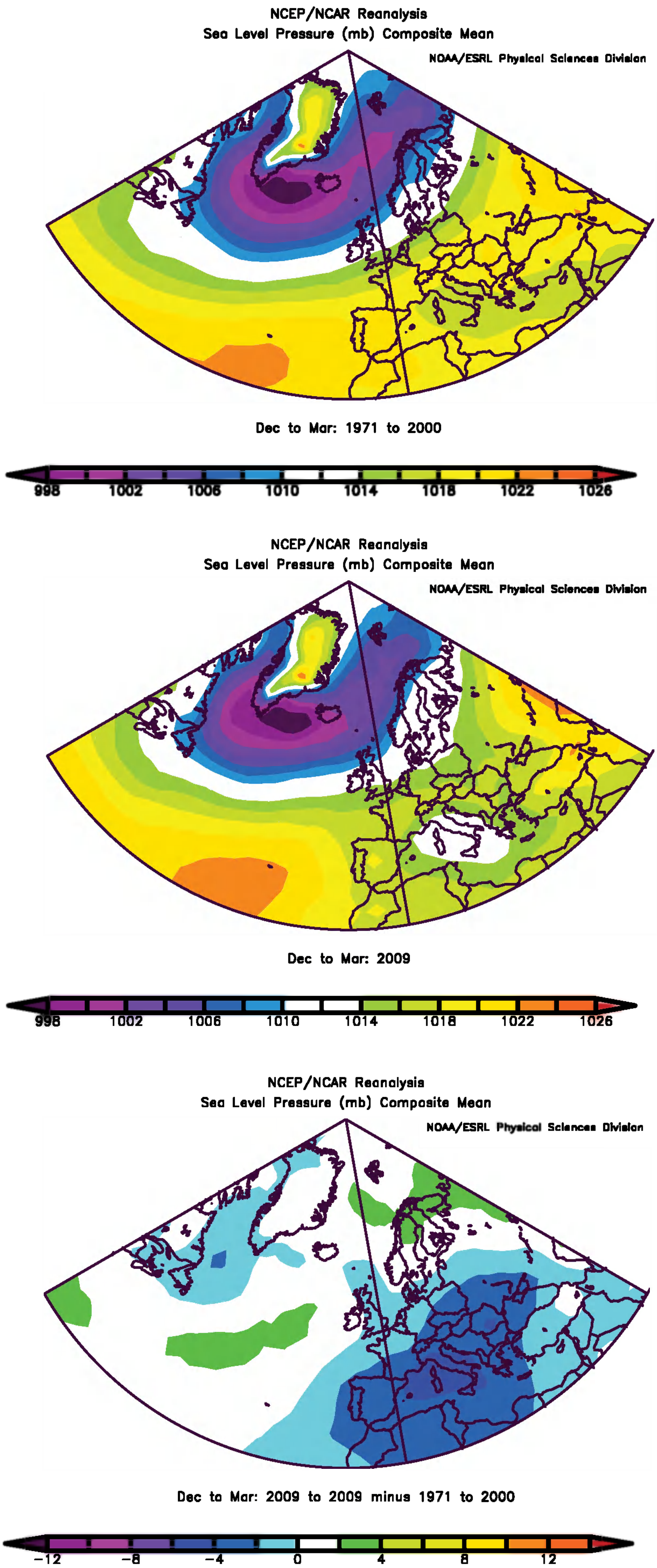
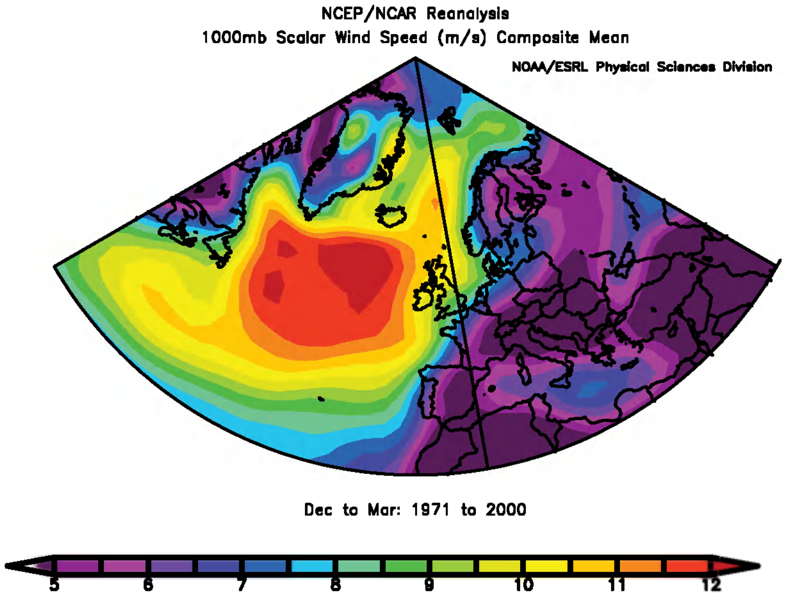


Figure 10.
Winter (DJFM) sea level pressure (SLP) fields. Top panel: SLP averaged over 30 years (1971–2000). Middle panel: mean SLP in winter 2009 (December 2008, January–March 2009). Bottom panel: winter 2009 SLP anomaly – the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO; available online at http://www.cdc.noaa.gov/.



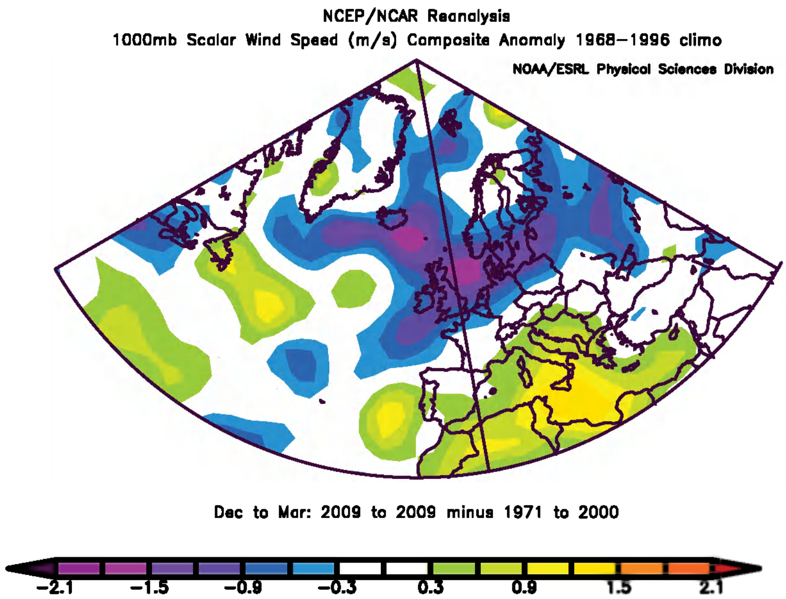


Figure 11.
Winter (DJFM) surface windspeed. Upper panel: surface windspeed averaged over 30 years (1971–2000). Lower panel: winter 2009 anomaly in surface windspeed. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO; available online at http://www.cdc.noaa.gov/.

3.2 Surface air temperature

North Atlantic winter mean surface air temperatures are shown in Figure 12. The 1971–2000 mean conditions (Figure 12, top panel) show warm temperatures penetrating far to the north on the eastern side of the North Atlantic and the Nordic seas, caused by the northward movement of warm oceanic water. The middle panel of Figure 12 shows the conditions in winter (DJFM) 2008/2009, and the bottom panel shows the difference between the two. In winter 2008/2009, the central North Atlantic and Norwegian Sea surface air temperatures were near normal. In contrast, the surface air temperature over the Labrador, Barents, and Greenland seas was more than 1°C warmer than normal.

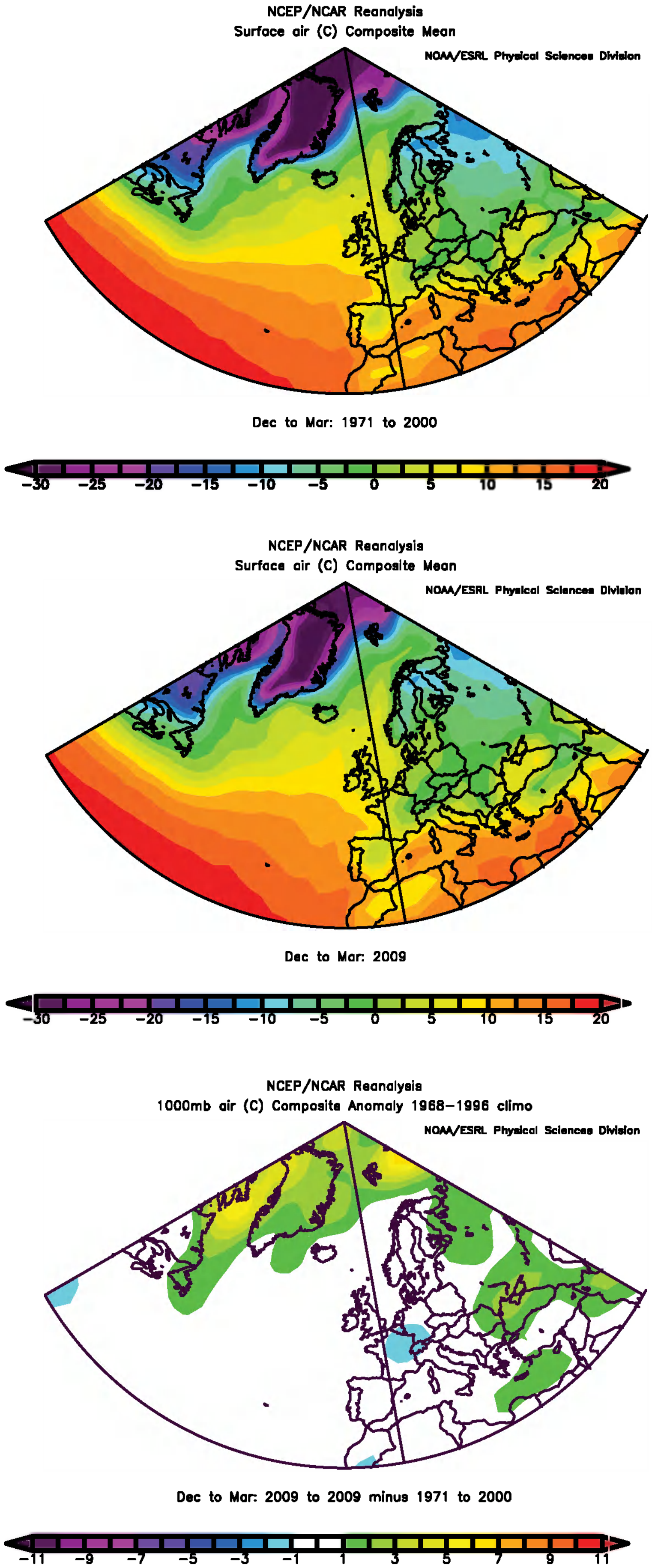


Figure 12.
Winter (DJFM) surface air temperature fields. Top panel: surface air temperature averaged over 30 years (1971–2000). Middle panel: temperatures in winter 2009 (December 2008, January to March 2009). Bottom panel: winter 2009 surface air temperature anomaly – the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO; available online at http://www.cdc.noaa.gov/.

4. DETAILED AREA DESCRIPTIONS, PART I: THE UPPER OCEAN

4.1 Introduction

In this section, we present time-series from many sustained observations in each of the ICES Areas. The general pattern of oceanic circulation in the upper layers of the North Atlantic, in relation to the areas described here, is given in Figure 13. In addition to temperature and salinity, we present other indices where they are available, such as air temperature and sea ice indices.The text summarizes the regional context of the sections and stations, noting any significant recent events.

Most standard sections or stations are sampled annually or more frequently. Often, the time-series presented here have been extracted from larger datasets and chosen as indicators of the conditions in a particular area. Where appropriate, data are presented as anomalies to demonstrate how the values compare with the average, or "normal", conditions (usually the long-term mean of each parameter during 1971–2000). For datasets that do not extend as far back as 1971, the average conditions have been calculated from the start of the dataset up to 2000.

In places, the seasonal cycle has been removed from a dataset, either by calculating the average seasonal cycle during 1971–2000 or by drawing on other sources, such as regional climatology datasets. Smoothed versions of most time-series are included using a "loess smoother", a locally weighted regression with a two- or five-year window.

In some areas, data are sampled regularly enough to allow a good description of the seasonal cycle. Where this is possible, monthly data from 2009 are presented and compared with the average seasonal conditions and statistics.

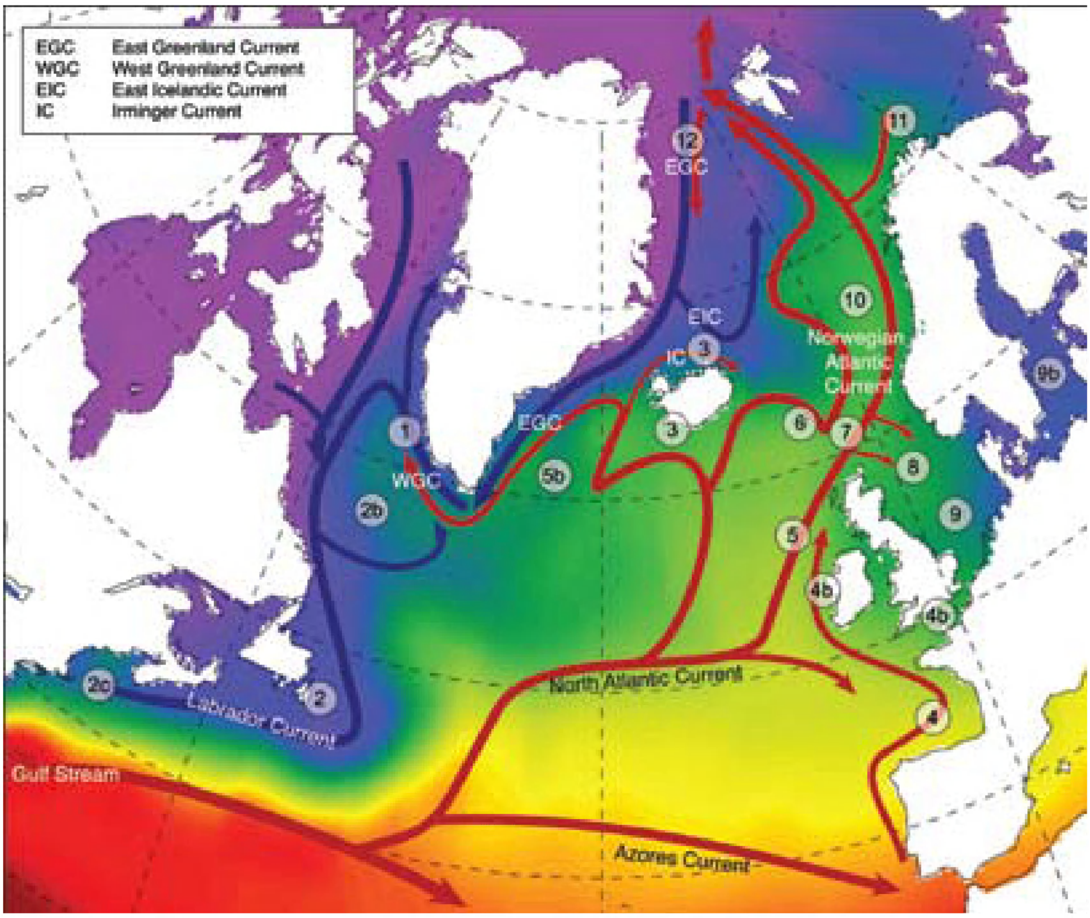


Figure 13.
Schematic of the general circulation of the upper ocean (0–1000 m) in the North Atlantic in relation to the numbered areas presented below. Blue arrows indicate the movement of the cooler waters of the Subpolar Gyre; red arrows indicate the movement of the warmer waters of the Subtropical Gyre.

4.2 Area 1 – West Greenland

WEST GREENLAND LIES AT THE NORTHERN BOUNDARY OF THE SUBPOLAR GYRE AND IS THUS SUBJECT TO CLIMATIC VARIATIONS WITHIN THIS GYRE. THE WEST GREENLAND CURRENT FOLLOWS THE CONTINENTAL SLOPE OFF WEST GREENLAND AND TRAVELS NORTHWARDS THROUGH DAVIS STRAIT. FYLLAS BANK STATION 4, LOCATED ON THE BANK SLOPE IN CA. 900M OF WATER, IS GOVERNED MOSTLY BY THE WARM COMPONENT OF THE WEST GREENLAND CURRENT (BELOW 150 M). IN SOME YEARS, SHALLOW SHELF WATER EXTENDS FARTHER OFFSHORE, BRINGING COLDER WATER TO STATION 4 (E.G. IN 1983, 1992, AND 2002). LOCATED FARTHER OFFSHORE, CAPE DESOLATION STATION 3 HAS A WATER COLUMN THAT IS 3000 M DEEP AND SAMPLES THE WEST GREENLAND CURRENT AND THE DEEP BOUNDARY CURRENT OF THE LABRADOR SEA.

West Greenland lies within an area that normally experiences warmer conditions when the NAO index is negative. In recent years, air temperature conditions around Greenland have been warmer than normal, despite the positive winter NAO index.

The mean air temperature in 2009 was 1.2°C above the mean for 1971–2000 and exceeded 1 standard deviation from its long-term mean. This reflected the air temperature over all of western Greenland and was consistent with the negative NAO index in winter 2008/2009. The high annual air temperature reflected warmer conditions in winter and summer, whereas the rest of the year was close to normal.

In 2009, the water temperature at 50 m depth at Cape Desolation Station 3 was 2.7°C higher than the long-term mean (1983–2000). This is the second highest value in the time-series. The 2009 salinity reached the highest value of the time-series, and these observations reflect the properties of the Irminger Sea water, which was unusually warm and salty with a very shallow core. The temperature, salinity, and volume of Irminger Sea water has been increasing at the section since the mid-1990s.

The temperature of the water layer at 0–200 m depth at Fyllas Bank Station 4 in the northern section was 1.2°C higher than the long-term mean (1983–2000). This also indicates that the Irminger Sea water was unusually warm, salty, and shallow at this location. The temperature and salinity of the Surface Polar Water, which normally flows in the upper 100 m, were close to their long-term means.

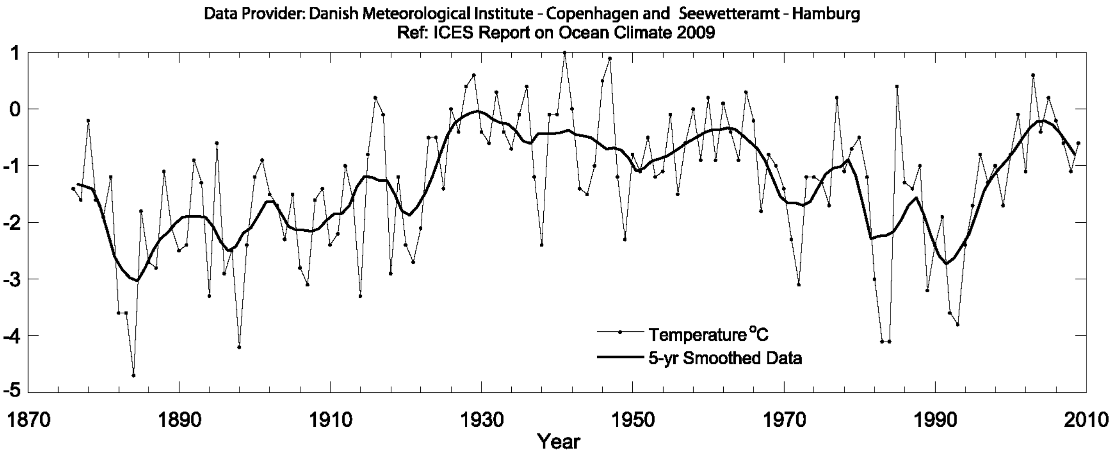


Figure 14. *Area 1 – West Greenland. Annual mean air temperature at Nuuk weather station (64.16°N 51.75°W).*

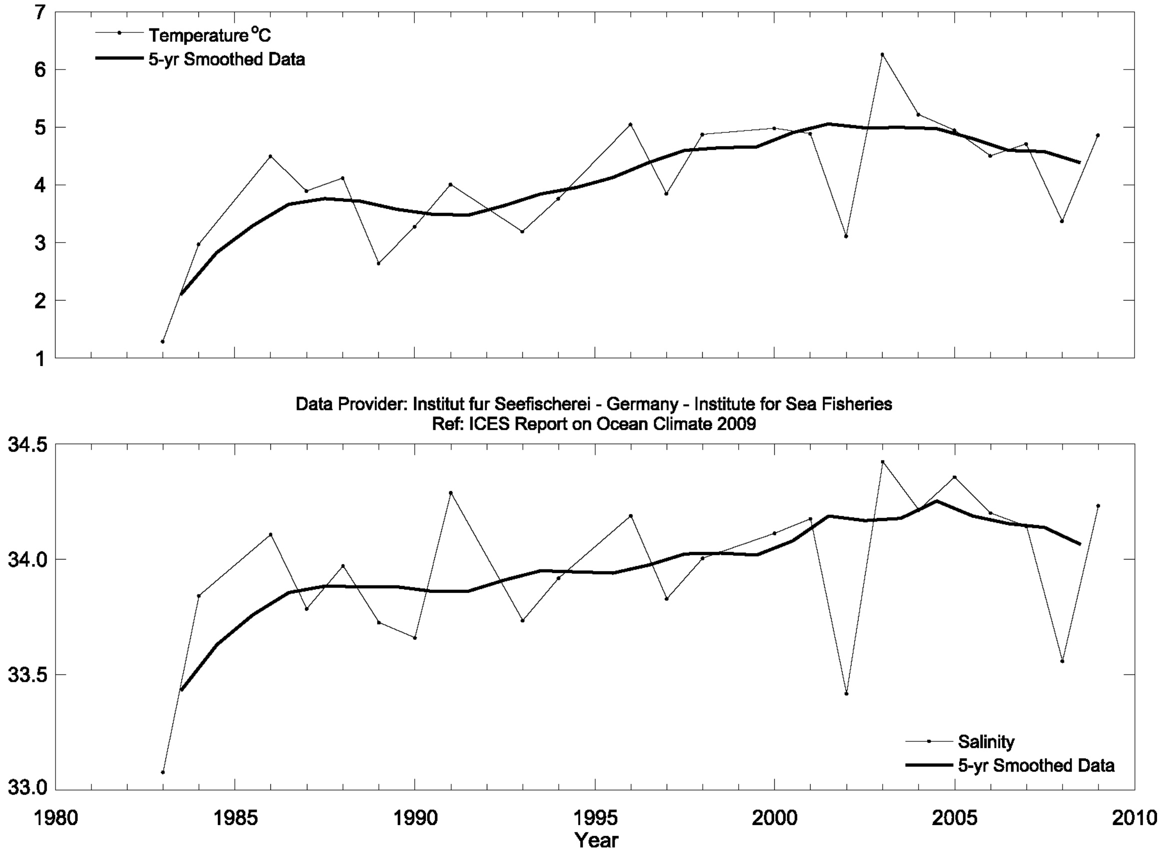


Figure 15.
Area 1 – West Greenland. Mean temperature (upper panel) and salinity (lower panel) in the 0–200 m water layer at Fyllas Bank Station 4 (63.88°N 53.37°W).

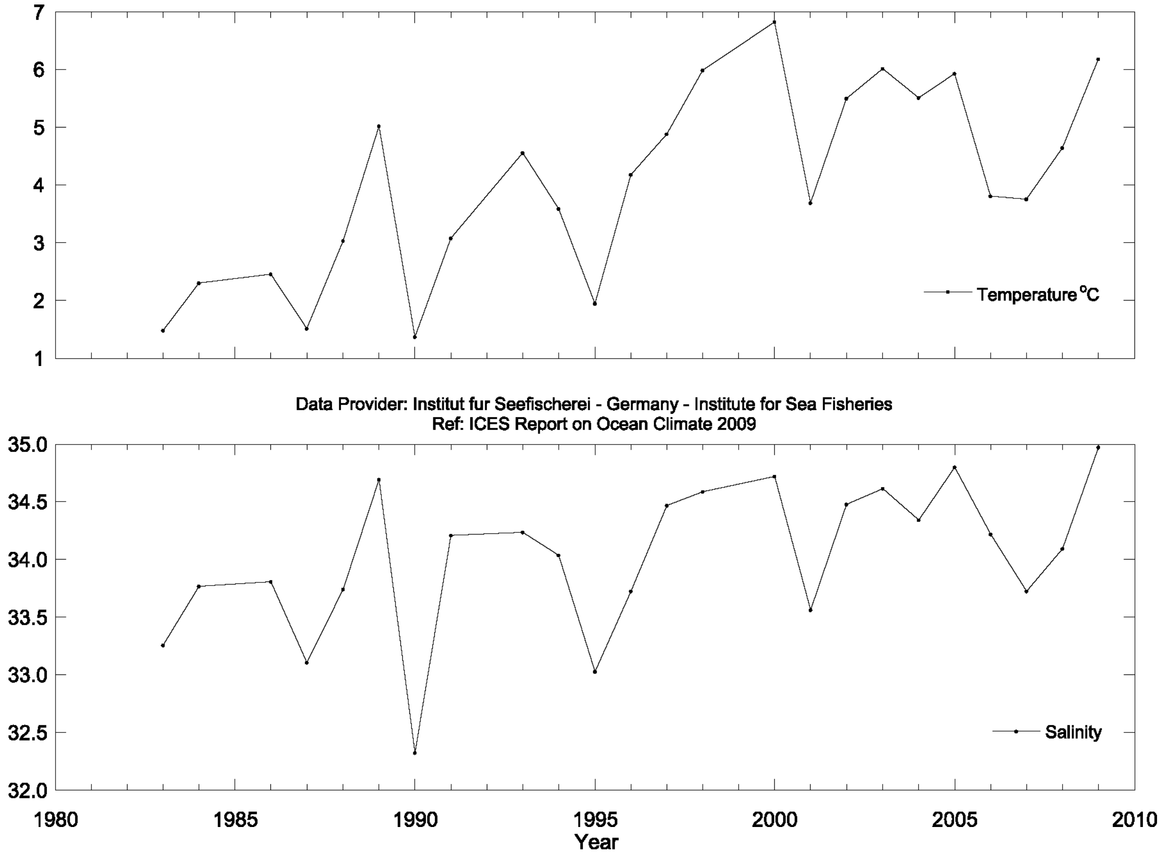


Figure 16.
Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 50 m at Cape Desolation Station 3 (60.45°N 50°W).

4.3 Area 2 – Northwest Atlantic: Scotian Shelf and the Newfoundland and Labrador Shelf

Scotian Shelf

THE CONTINENTAL SHELF OFF THE COAST OF NOVA SCOTIA IS CHARACTERIZED BY COMPLEX TOPOGRAPHY CONSISTING OF MANY OFFSHORE SHALLOW BANKS AND DEEP MID-SHELF BASINS. IT IS SEPARATED FROM THE SOUTHERN NEWFOUNDLAND SHELF BY THE LAURENTIAN CHANNEL AND BORDERS THE GULF OF MAINE TO THE SOUTHWEST. SURFACE CIRCULATION IS DOMINATED BY A GENERAL FLOW TOWARDS THE SOUTHWEST, INTERRUPTED BY CLOCKWISE MOVEMENT AROUND THE BANKS AND ANTICLOCKWISE MOVEMENT AROUND THE BASINS, WITH THE STRENGTHS VARYING SEASONALLY.

HYDROGRAPHIC CONDITIONS ON THE SCOTIAN SHELF ARE DETERMINED BY HEAT TRANSFER BETWEEN THE OCEAN AND ATMOSPHERE, INFLOW FROM THE GULF OF ST LAWRENCE AND THE NEWFOUNDLAND SHELF, AND EXCHANGE WITH OFFSHORE SLOPE WATERS. WATER PROPERTIES HAVE LARGE SEASONAL CYCLES AND ARE MODIFIED BY FRESHWATER RUN-OFF, PRECIPITATION, AND MELTING OF SEA ICE. TEMPERATURE AND SALINITY EXHIBIT STRONG HORIZONTAL AND VERTICAL GRADIENTS THAT ARE MODIFIED BY DIFFUSION, MIXING, CURRENTS, AND SHELF TOPOGRAPHY.

In 2009, annual mean air temperatures over the Scotian Shelf, represented by Sable Island observations, were 0.5°C, corresponding to a 0.7 standard deviation (s.d.) above the long-term mean (1971–2000). The amount of sea ice on the Scotian Shelf in 2009, as measured by the total area of ice seawards of Cabot Strait between Nova Scotia and Newfoundland from January to April, was 34 000 km^2, close to the long-term mean coverage of 39 000 km^2. This is twice the 2008 ice cover.

Topography separates the northeastern Scotian Shelf from the rest of the shelf. In the northeast, the bottom tends to be covered by relatively cold waters (1–4°C), whereas the basins in the central and southwestern regions typically have bottom-water temperatures of 8–10°C. The origin of the latter is the offshore slope waters, whereas in the northeast, the water comes principally from the Gulf of St Lawrence. The interannual variability of the two water masses differs. Measurements of temperatures at 100 m at the Misaine Bank station capture the changes in the northeast. They reveal average conditions in 2009, with temperatures slightly above normal (by 0.25°C, 0.4 s.d.) and salinity below normal (by 0.11, –0.8 s.d.). In Emerald Basin, temperatures in 2009 were below normal at 250 m by –1.3°C (1.6 s.d.) and salinity was below normal (by 0.2, –1.3 s.d.).

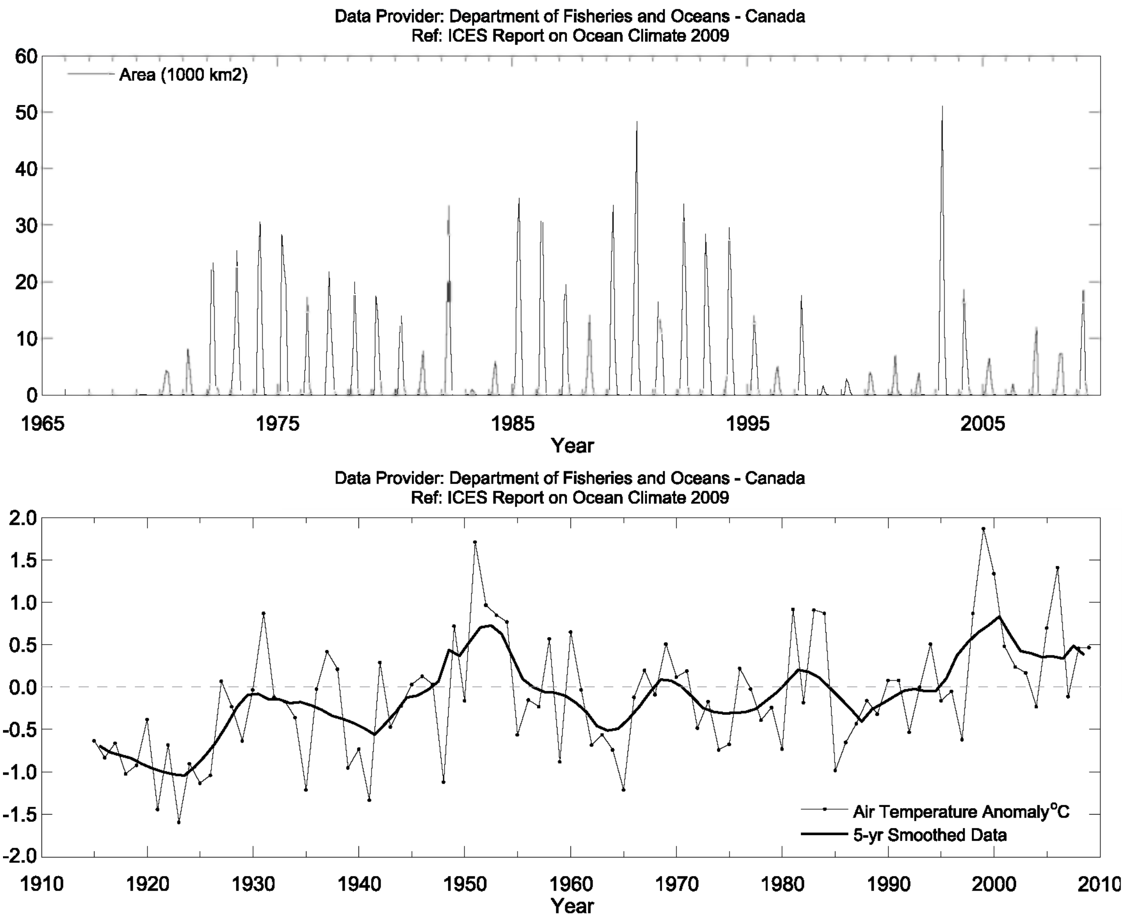


Figure 17. *Area 2 – Northwest Atlantic: Scotian Shelf. Monthly means of ice area seawards of Cabot Strait (upper panel) and air temperature at Sable Island on the Scotian Shelf (lower panel).*

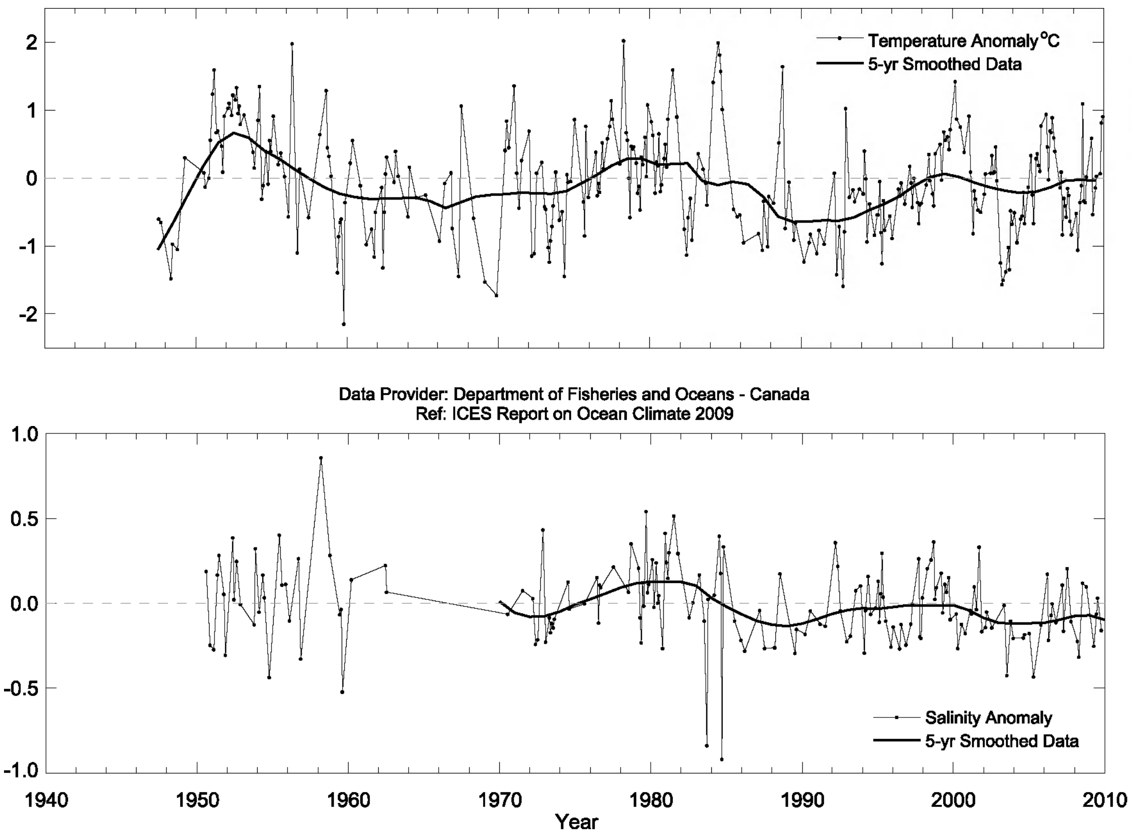


Figure 18.
Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature anomalies (upper panel) and salinity anomalies (lower panel) at Misaine Bank (100 m).

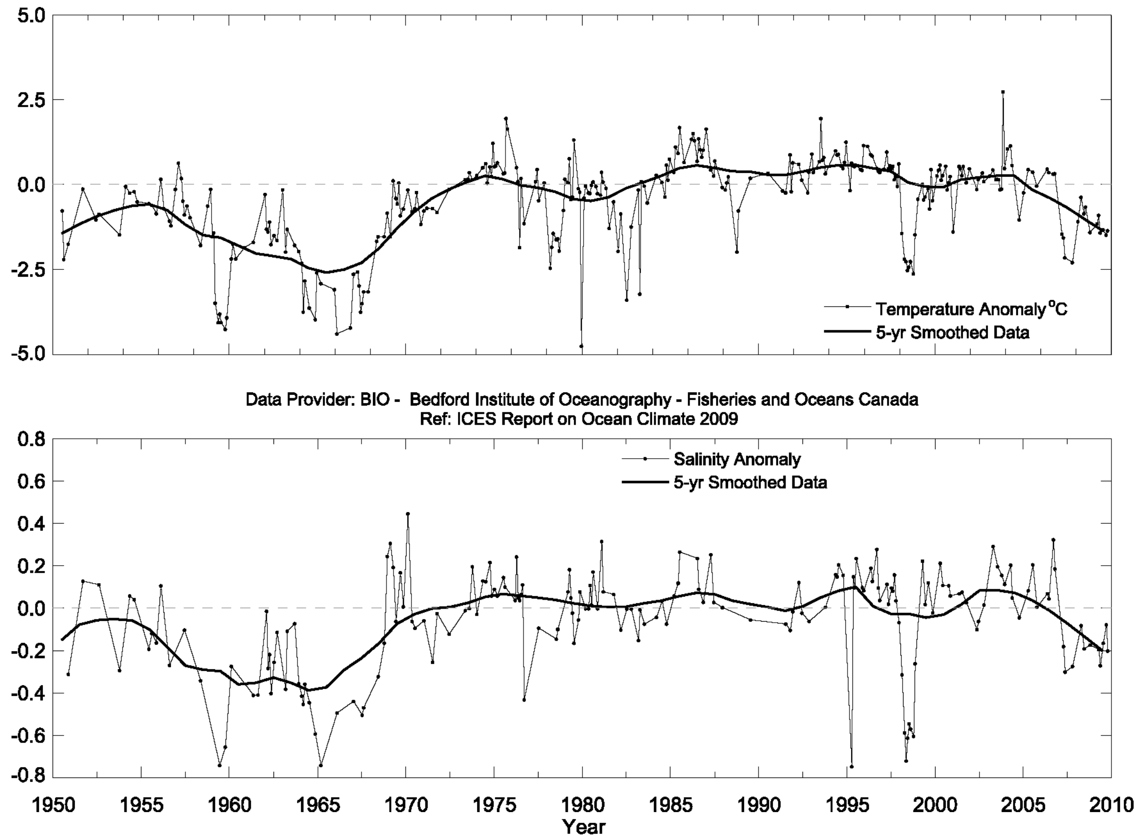


Figure 19.
Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature anomalies (upper panel) and salinity anomalies (lower panel) in the central Scotian Shelf (Emerald Basin 250 m).

Newfoundland and Labrador Shelf

THIS REGION IS SITUATED ON THE WESTERN SIDE OF THE LABRADOR SEA, STRETCHING FROM HUDSON STRAIT TO THE SOUTHERN GRAND BANK AND DOMINATED BY SHALLOW BANKS, CROSS-SHELF CHANNELS OR SADDLES, AND DEEP MARGINAL TROUGHS NEAR THE COAST. CIRCULATION IS DOMINATED BY THE SOUTH-FLOWING LABRADOR CURRENT BRINGING COLD, FRESH WATERS FROM THE NORTH, TOGETHER WITH SEA ICE AND ICEBERGS, TO SOUTHERN AREAS OF THE GRAND BANKS.

HYDROGRAPHIC CONDITIONS ARE DETERMINED BY THE STRENGTH OF THE WINTER ATMOSPHERIC CIRCULATION OVER THE NORTHWEST ATLANTIC (NAO), ADVECTION BY THE LABRADOR CURRENT, CROSS-SHELF EXCHANGE WITH WARMER CONTINENTAL SLOPE WATER, AND BOTTOM TOPOGRAPHY. SUPERIMPOSED ARE LARGE SEASONAL AND INTERANNUAL VARIATIONS IN SOLAR HEAT INPUT, SEA-ICE COVER, AND STORM-FORCED MIXING. THE RESULTING WATER MASS ON THE SHELF EXHIBITS LARGE ANNUAL CYCLES WITH STRONG HORIZONTAL AND VERTICAL TEMPERATURE AND SALINITY GRADIENTS.

The NAO index for 2009 (Iceland–Azores) was close to the long-term mean; as a consequence, the outflow of Arctic air masses to the Northwest Atlantic during winter (December–February) returned to normal. This resulted in a slight increase in air temperatures throughout the Northwest Atlantic, from West Greenland to Baffin Island and to Labrador and Newfoundland, relative to 2008, when the NAO index was 0.5 s.d. above normal. Annual air temperatures were above normal at Labrador (1°C at Cartwright) and Newfoundland (1.4°C at St John's), but showed a significant decrease from the record highs of 2006. The annual sea ice extent on the Newfoundland and Labrador Shelf remained below normal for the 15th consecutive year. However, the spring extent was the highest since 1994.

Local water temperatures on the Newfoundland and Labrador Shelf continued to demonstrate a slight cooling trend, but remained above normal in some areas in 2009. At the standard monitoring site off eastern Newfoundland (Station 27), the depth-averaged annual water temperature decreased from the record high observed in 2006 to only slightly above normal (<0.5 s.d.) in 2009. Annual surface temperatures at Station 27 also decreased from the 64-year record of 1.7°C (3 s.d.) above normal in 2006 to ca. 0.4°C (0.7 s.d.) above normal in 2009. Bottom temperatures (176 m) at Station 27 were slightly below normal in 2009. Upper-layer salinities at Station 27 were above normal for the eighth consecutive year; however, they decreased from 2008 values.

A robust index of ocean climate conditions in eastern Canadian waters is the extent of the cold intermediate layer (CIL) of <0°C water overlying the continental shelf. This winter-cooled water is isolated between the seasonally heated upper layer and the warmer shelf-slope water throughout summer and autumn. During the 1960s, when the NAO was well below normal and had the lowest value ever in the 20th century, the volume of CIL water was at a minimum, but during the high NAO years of the early 1990s, the CIL volume reached almost record-high values. The area of the CIL water mass on the Newfoundland Shelf during 2009 was below normal (<0.5 s.d.) for the 15th consecutive year, implying warm conditions, whereas off southern Labrador, it was above normal (cold conditions) by 0.6 s.d., the largest since 1994.

In summary, ocean temperatures on the Newfoundland and Labrador Shelf have decreased from the record highs of 2006, but remained above normal in most areas during 2007–2008. In 2009, they decreased further, with some indices demonstrating negative anomalies. A composite climate index, derived from several meteorological, sea-ice, and oceanographic temperature and salinity time-series, indicated a peak in 2006, but this has decreased in recent years, with 2008 ranking sixth highest and 2009 ranking 34th in 60 years of observations. The composite index is a measure of the overall state of the climate system, with positive values generally representing warm-saline conditions and negative representing cold-fresh conditions.

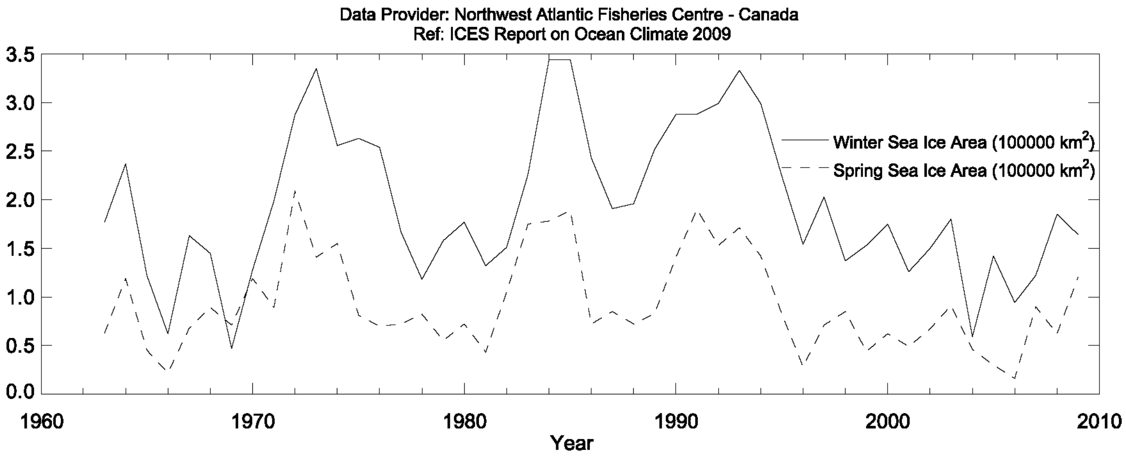


Figure 20.
Area 2 – Northwest Atlantic: Newfoundland and Labrador Shelf. Monthly sea-ice areas off Newfoundland and Labrador between 45°N and 55°N.

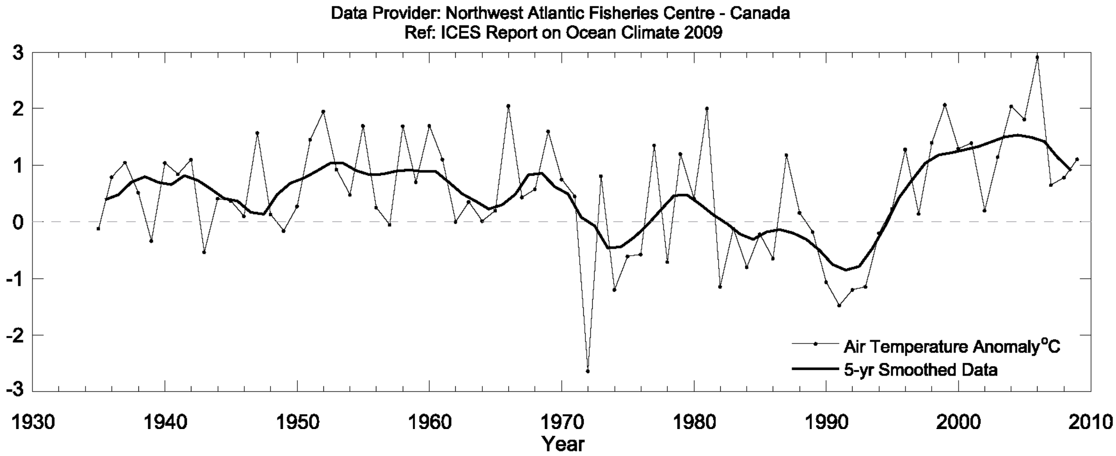


Figure 21.
Area 2 – Northwest Atlantic: Newfoundland and Labrador Shelf. Annual air temperature anomalies at Cartwright on the Labrador coast.

OCEAN TEMPERATURES ON THE NEWFOUNDLAND AND LABRADOR SHELF RETURN TO NEAR-NORMAL FROM PEAK IN 2006.

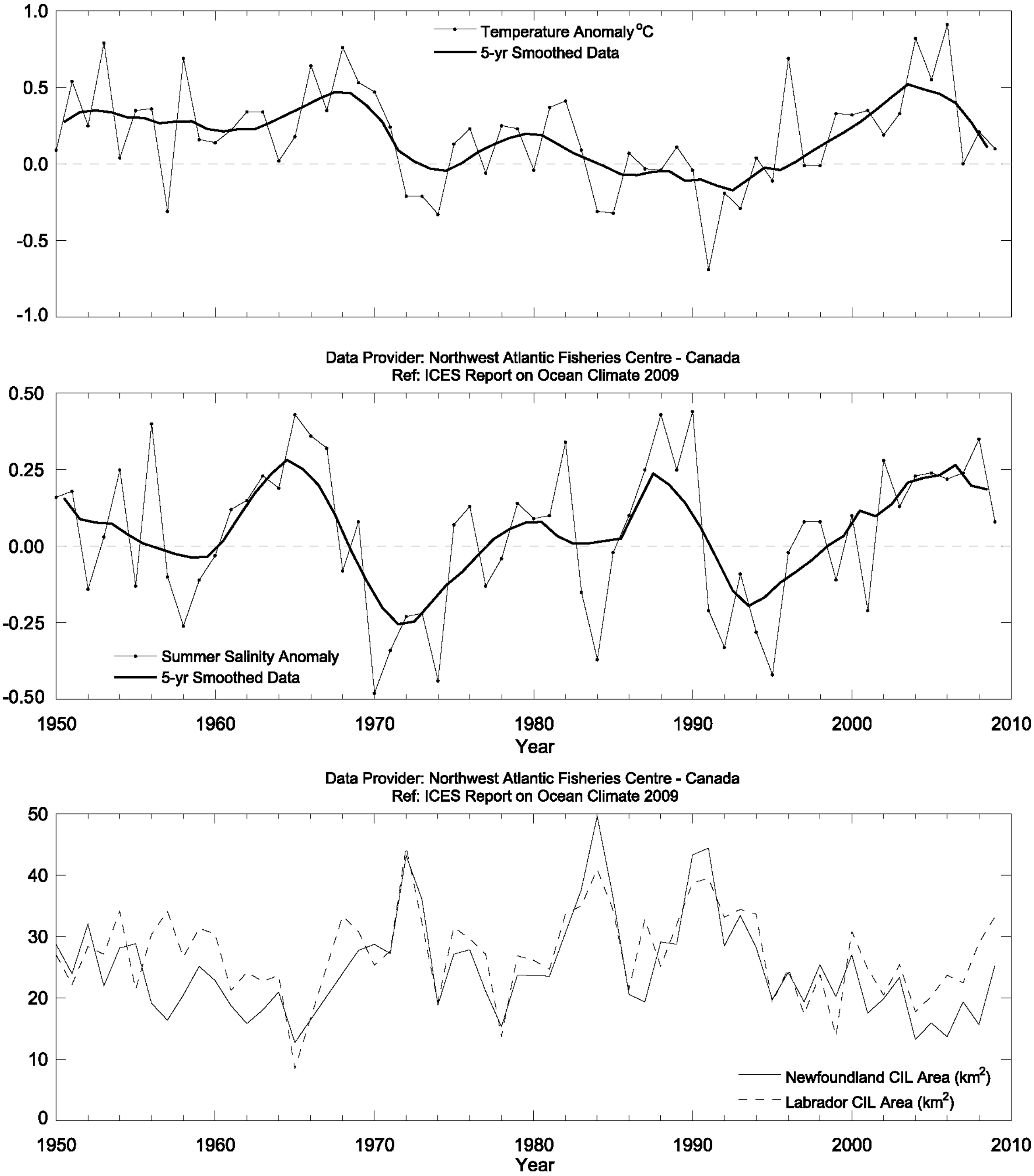


Figure 22.
Area 2 – Northwest Atlantic: Newfoundland and Labrador Shelf. Annual depth-averaged Newfoundland Shelf temperature anomalies (top panel), salinity anomalies (middle panel), and spatial extent of cold intermediate layer (CIL; bottom panel).

4.4 Area 2b – Labrador Sea

THE LABRADOR SEA IS LOCATED BETWEEN GREENLAND AND THE LABRADOR COAST OF EASTERN CANADA. COLD, LOW-SALINITY WATERS OF POLAR ORIGIN CIRCLE THE LABRADOR SEA IN AN ANTICLOCKWISE CURRENT SYSTEM THAT INCLUDES BOTH THE NORTH-FLOWING WEST GREENLAND CURRENT ON THE EASTERN SIDE AND THE SOUTH-FLOWING LABRADOR CURRENT ON THE WESTERN SIDE. WARM AND SALINE ATLANTIC WATERS ORIGINATING IN THE SUBTROPICS FLOW NORTH INTO THE LABRADOR SEA ON THE GREENLAND SIDE AND BECOME COLDER AND FRESHER AS THEY CIRCULATE.

CHANGES IN LABRADOR SEA HYDROGRAPHIC CONDITIONS ON INTERANNUAL TIME-SCALES DEPEND ON THE VARIABLE INFLUENCES OF HEAT LOSS TO THE ATMOSPHERE, HEAT AND SALT GAIN FROM ATLANTIC WATERS, AND FRESHWATER GAIN FROM MELTING ARCTIC SEA ICE. A SEQUENCE OF SEVERE WINTERS IN THE EARLY 1990S LED TO DEEP CONVECTION PEAKING IN 1993–1994 THAT FILLED THE UPPER 2 KM OF THE WATER COLUMN WITH COLD, FRESH WATER. CONDITIONS HAVE BEEN MILDER IN RECENT YEARS. THE UPPER LEVELS OF THE LABRADOR SEA HAVE BECOME WARMER AND MORE SALINE AS HEAT LOSSES TO THE ATMOSPHERE HAVE DECREASED AND ATLANTIC WATERS HAVE BECOME INCREASINGLY DOMINANT.

The upper 150 m of the west-central Labrador Sea warmed by ~1°C and increased in salinity by ~0.1 during the 1990s. Temperatures have been relatively stable in recent years, whereas salinity continues to increase. Following a warm winter, air temperatures in spring and summer 2009 were the coldest since the early 2000s, and the upper layer of the sea cooled by 0.6°C compared with 2008 conditions.

The 2009 annual mean SST in the west-central Labrador Sea was the lowest observed since 2000, but still exceeded the long-term 1971–2000 mean by 0.3°C. This was the 16th consecutive year that was warmer than normal, but there is a suggestion of a recent cooling trend. Each of the past three years, including 2008, was cooler than any during 2003–2006.

TEMPERATURES IN THE LABRADOR SEA JUST ABOVE NORMAL, BUT SALINITY HIGH.

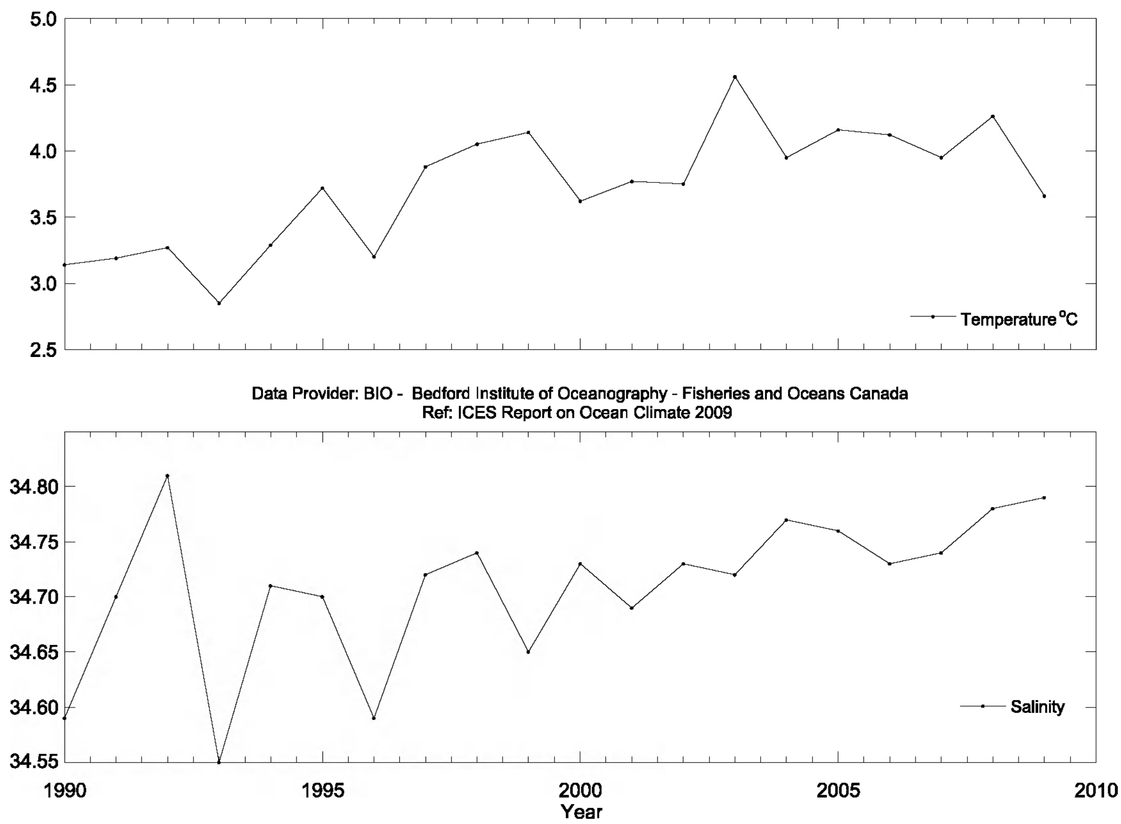


Figure 23.
Area 2b – Labrador Sea. Potential temperature (upper panel) and salinity (lower panel) at 0–150 m, from four stations in the west-central Labrador Sea (centred at 56.7°N 52.5°W). Estimates of seasonal changes based on climatology have been removed from these spring/early summer measurements.

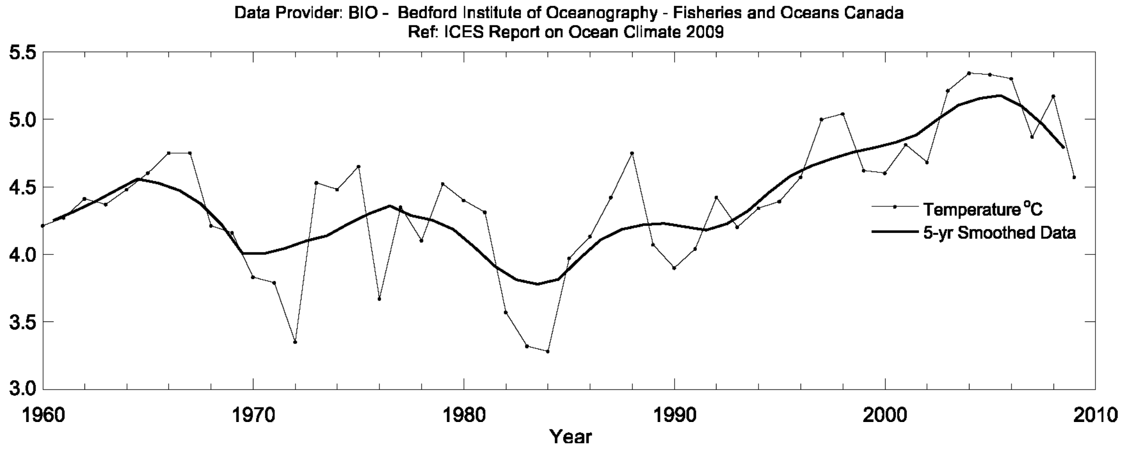


Figure 24.
Area 2b – Labrador Sea. Annual mean sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 sea ice and sea surface temperature dataset, UK Meteorological Office, Hadley Centre.

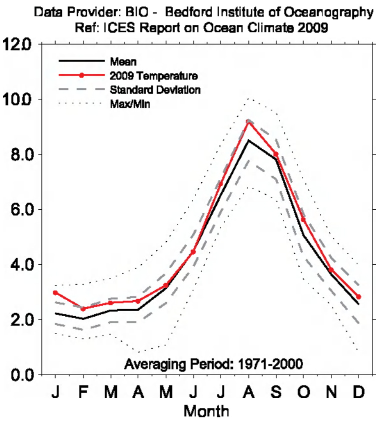


Figure 25.
Area 2b – Labrador Sea. 2009 monthly sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 sea ice and sea surface temperature dataset, UK Meteorological Office, Hadley Centre.

4.5 Area 2c – Mid-Atlantic Bight

THE HYDROGRAPHIC CONDITIONS IN THE WESTERN SLOPE SEA, THE MID-ATLANTIC BIGHT, AND THE GULF OF MAINE DEPEND ON THE SUPPLY OF WATERS FROM THE LABRADOR SEA, ALONG BOTH THE SHELF AND THE CONTINENTAL SLOPE. THESE WATERS HAVE BEEN MONITORED BY REGULAR EXPENDABLE BATHYTHERMOGRAPH (XBT) AND SURFACE SALINITY OBSERVATIONS FROM COMMERCIAL AND FISHING VESSELS SINCE 1978. ONE SECTION RUNS SOUTHEAST OF NEW YORK CITY TO BERMUDA AND THE OTHER TRAVERSES THE GULF OF MAINE, EAST OF BOSTON. HYDROGRAPHIC CONDITIONS THROUGHOUT THE SHELF, INCLUDING GEORGES BANK, HAVE ALSO BEEN MONITORED ANNUALLY SINCE 1977 BY BOTTOM-TRAWL SURVEYS.

Figure 27 shows surface temperature and bottom temperature anomalies along the XBT line southeast of New York City. In 2009, conditions at the surface became closer to the climatological mean after generally warm conditions the previous year, especially over the central shelf. Bottom temperatures stayed generally warm, as they have been since 2006. Figure 28 shows surface temperature and bottom temperature anomalies along the XBT line across the Gulf of Maine. Surface conditions have stayed generally warm, as they have been since 2006. Bottom temperatures demonstrated a more complex pattern of warm and cold anomalies, but, overall, were warmer than in the previous year.

The Georges Bank surface observations (0–30 m) come from a wide region covering the bank. Figure 29 shows temperature and salinity anomalies. The anomalies are in original units relative to the mean for 1977–2000. The conditions on the bank in 2009 were generally close to the long-term climatological conditions (especially the salinity, where the anomaly is indistinguishable from zero).

SURFACE WATERS IN THE GULF OF MAINE WARMER THAN AVERAGE FOR THE PAST FOUR YEARS.

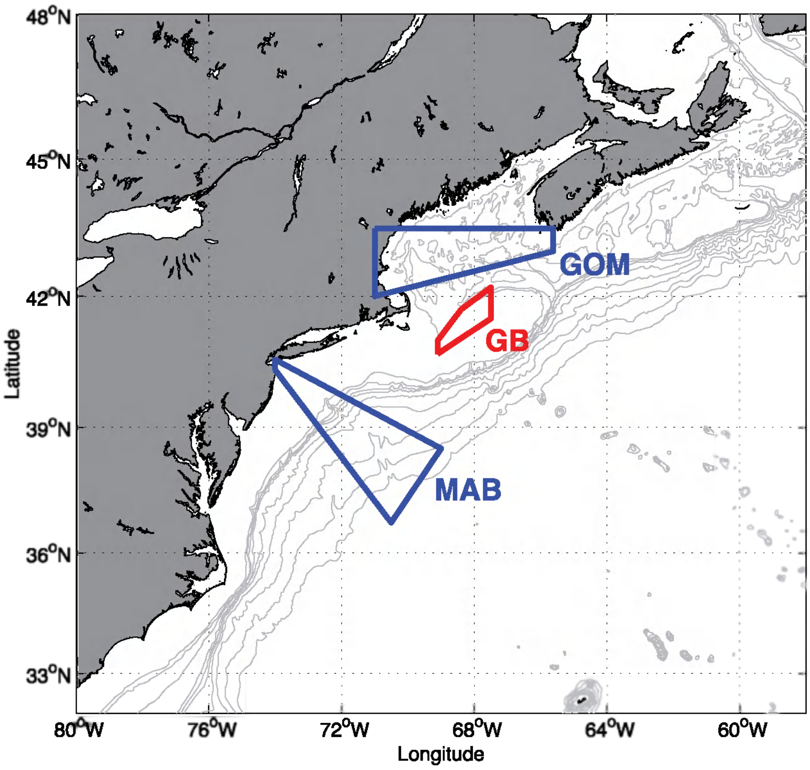


Figure 26.
Area 2c – Mid-Atlantic Bight. The three regions of ongoing time-series: GOM = Gulf of Maine (XBT measurements and surface samples); GB = Georges Bank (CTD stations); MAB = central Mid-Atlantic Bight (XBT measurements and surface samples). The isobaths shown range from 100 to 500 m by 100 m increments, and from 1000 to 4000 m by 500 m increments. Data provider: National Marine Fisheries Service, USA.

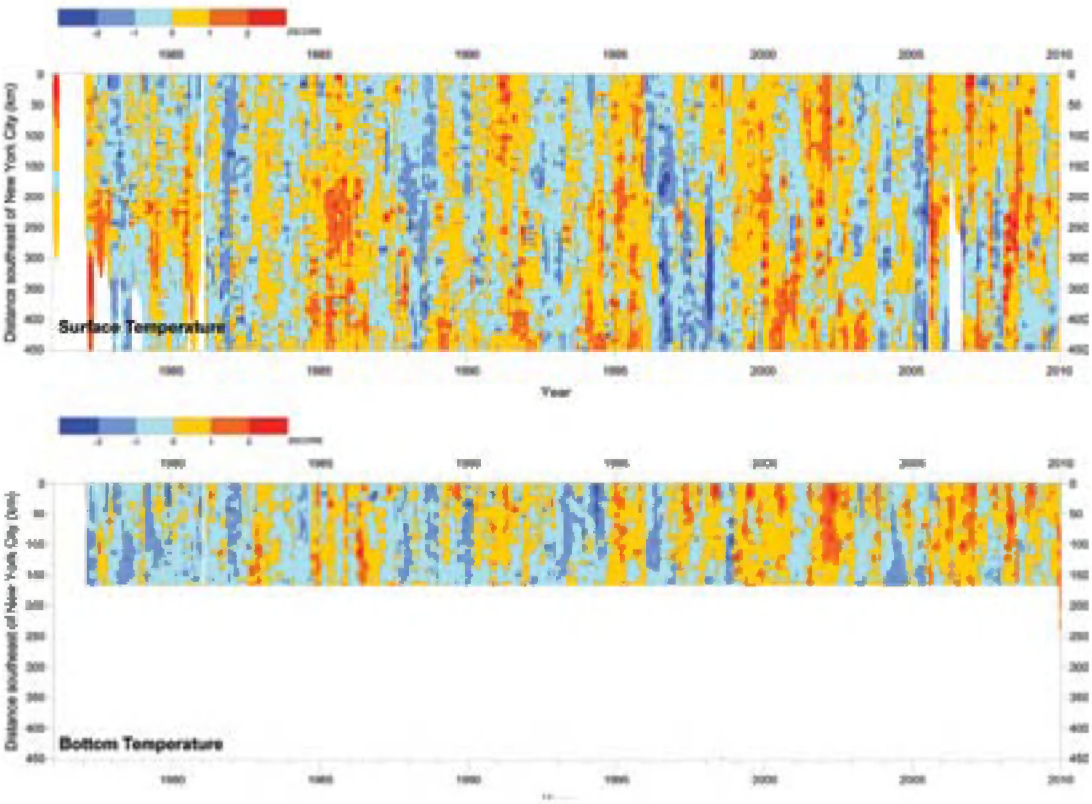


Figure 27.
Area 2c – Mid-Atlantic Bight. Surface and bottom temperatures in the central Mid-Atlantic Bight. Upper panel: surface temperature anomaly (relative to the base period of 1978–2007) from XBT measurements; the origin of the line is New York City. Lower panel: bottom temperature anomaly from XBT measurements. Data provider: National Marine Fisheries Service, USA. The data are truncated at 160 km to avoid artefacts resulting from incursions of shelf/slope and Gulf Stream fronts.

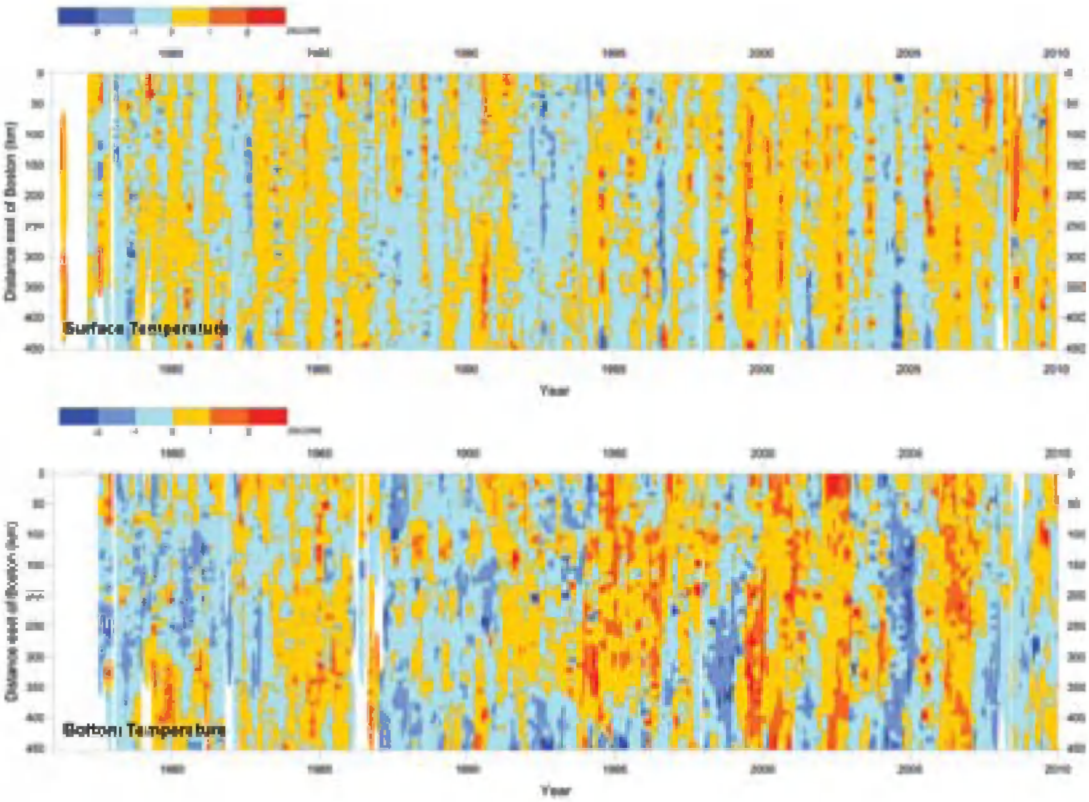


Figure 28.
Area 2c – Mid-Atlantic Bight. Surface and bottom temperature in the Gulf of Maine. Upper panel: surface temperature anomaly (relative to the base period of 1978–2007) from XBT measurements; the origin of the line is Boston. Lower panel: bottom temperature anomaly from XBT measurements. Data provider: National Marine Fisheries Service, USA.

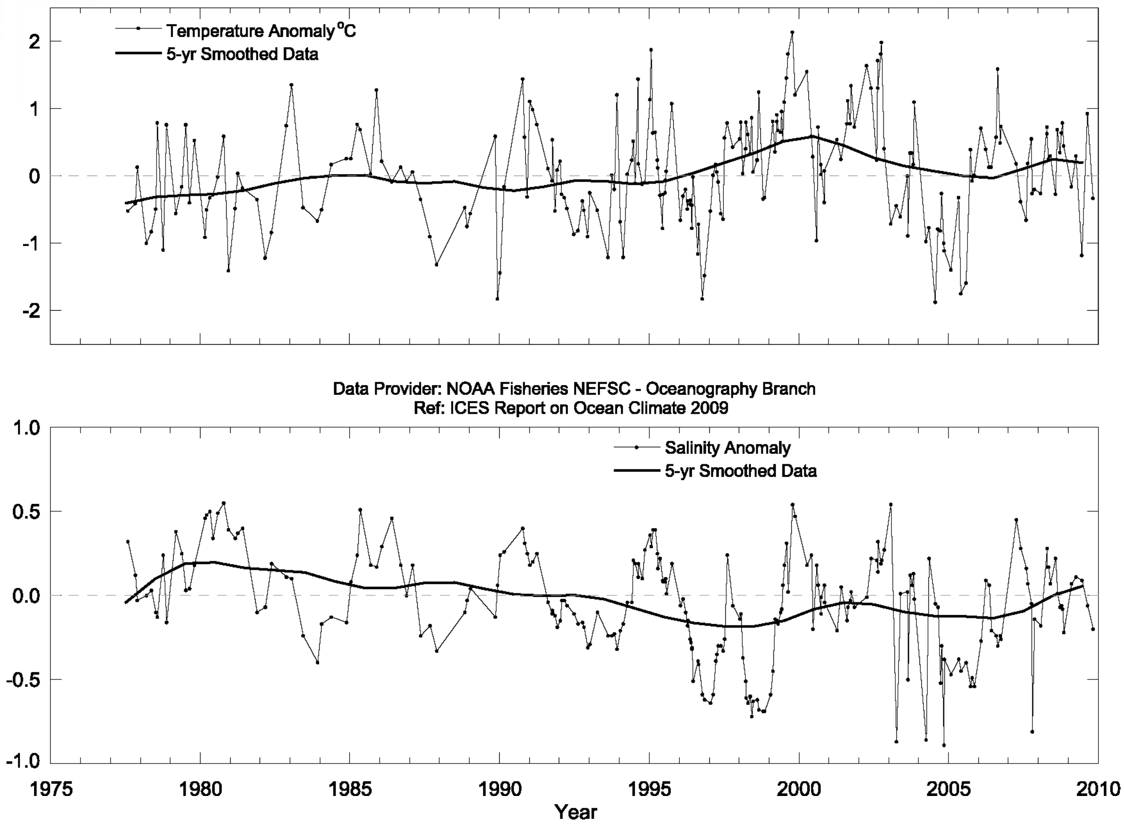


Figure 29.
Area 2c – Mid-Atlantic Bight. Time-series plots of 0–30 m averaged temperature anomaly (upper panel) and salinity anomaly (lower panel) at Georges Bank. Data provider: National Marine Fisheries Service, USA.

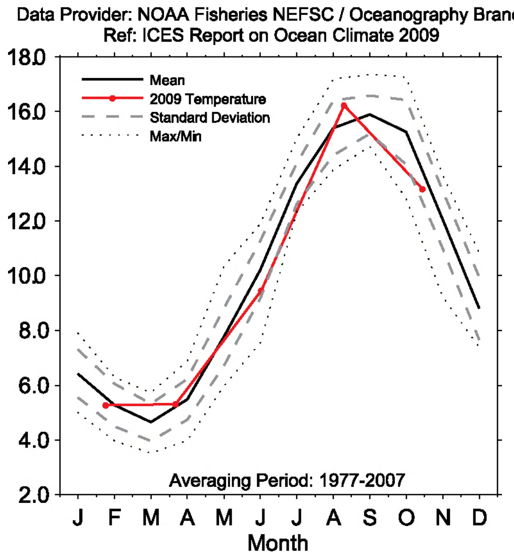


Figure 30.
Area 2c – Mid-Atlantic Bight. 2009 monthly temperatures (0–30 m) at Georges Bank.

Voluntary observing ships

- Many of the data presented here are collected from commercial vessels that voluntarily make ocean measurements along their journeys. The results from monthly sampling of surface and bottom temperatures for nearly three decades reveal the power of systematic or repeat sampling from merchant marine vessels. A number of vessels are now operating automated systems to sample temperature and salinity while underway. The key to success with these is to ensure that the data become available as soon as the vessel makes a port call. There is a pressing need for merchant-marine-optimized techniques to track and report data from the ocean in a timely fashion.

The section east of Boston has depended upon observations from various vessels, including those from Eimskipafelag, Caribou Seafoods, the US Coast Guard, and Hans Speck and Son. Their cooperation is greatly appreciated.

Deployment of CTD from RV Polarstern. Image courtesy of Agnieszka Beszczynska-Möller, AWI, Germany.

4.6 Area 3 – Icelandic Waters

ICELAND IS AT THE MEETING PLACE OF WARM AND COLD CURRENTS. THESE CONVERGE IN AN AREA OF SUBMARINE RIDGES (GREENLAND–SCOTLAND RIDGE, REYKJANES RIDGE, KOLBEINSEY RIDGE) THAT FORM NATURAL BARRIERS TO THE MAIN OCEAN CURRENTS. THE WARM IRMINGER CURRENT, A BRANCH OF THE NORTH ATLANTIC CURRENT (6–8°C), FLOWS FROM THE SOUTH, AND THE COLD EAST GREENLAND AND EAST ICELANDIC CURRENTS (–10°C TO 2°C) FLOW FROM THE NORTH. DEEP BOTTOM CURRENTS IN THE SEAS AROUND ICELAND ARE PRINCIPALLY THE OVERFLOW OF COLD WATER FROM THE NORDIC SEAS AND THE ARCTIC OCEAN OVER THE SUBMARINE RIDGES INTO THE NORTH ATLANTIC.

HYDROGRAPHIC CONDITIONS IN ICELANDIC WATERS ARE GENERALLY CLOSELY RELATED TO ATMOSPHERIC OR CLIMATIC CONDITIONS IN AND OVER THE COUNTRY AND THE SURROUNDING SEAS, MAINLY THROUGH THE ICELAND LOW-PRESSURE AND GREENLAND HIGH-PRESSURE SYSTEMS. THESE CONDITIONS IN THE ATMOSPHERE AND THE SURROUNDING SEAS AFFECT BIOLOGICAL CONDITIONS, EXPRESSED THROUGH THE FOOD CHAIN IN THE WATERS, INCLUDING RECRUITMENT AND ABUNDANCE OF COMMERCIALLY IMPORTANT FISH STOCKS.

In 2009, mean air temperatures in the south (Reykjavik) and north (Akureyri) were above the long-term averages. During the year, temperature and salinity levels south and west of Iceland remained high, with the highest salinity in almost 40 years occurring in 2009. In the north, summer and autumn temperatures and salinities of surface layers were above average. Salinity and temperature in the East Icelandic Current in spring 2009 were above average.

TEMPERATURE AND SALINITY AROUND ICELAND ABOVE AVERAGE IN 2009.

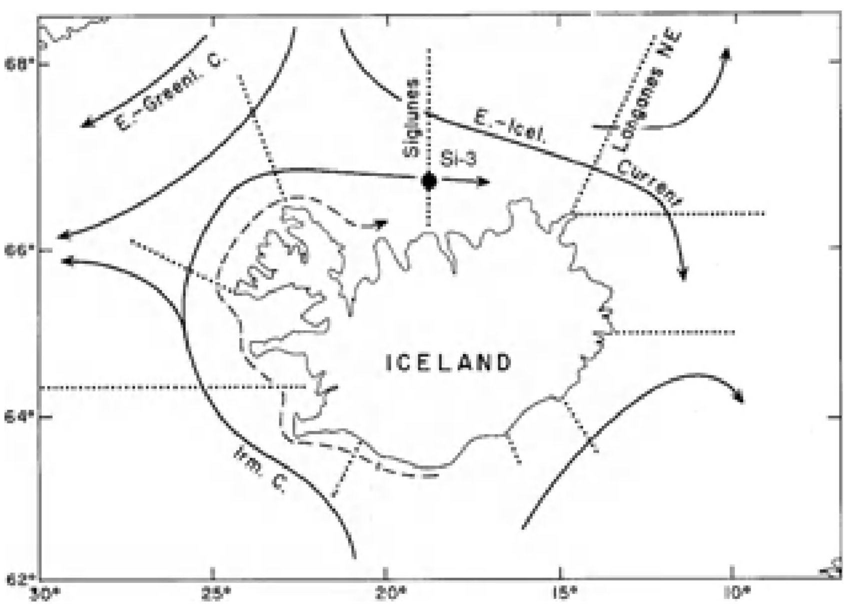


Figure 31.
Area 3 – Icelandic waters. Main currents and location of standard sections in Icelandic waters.

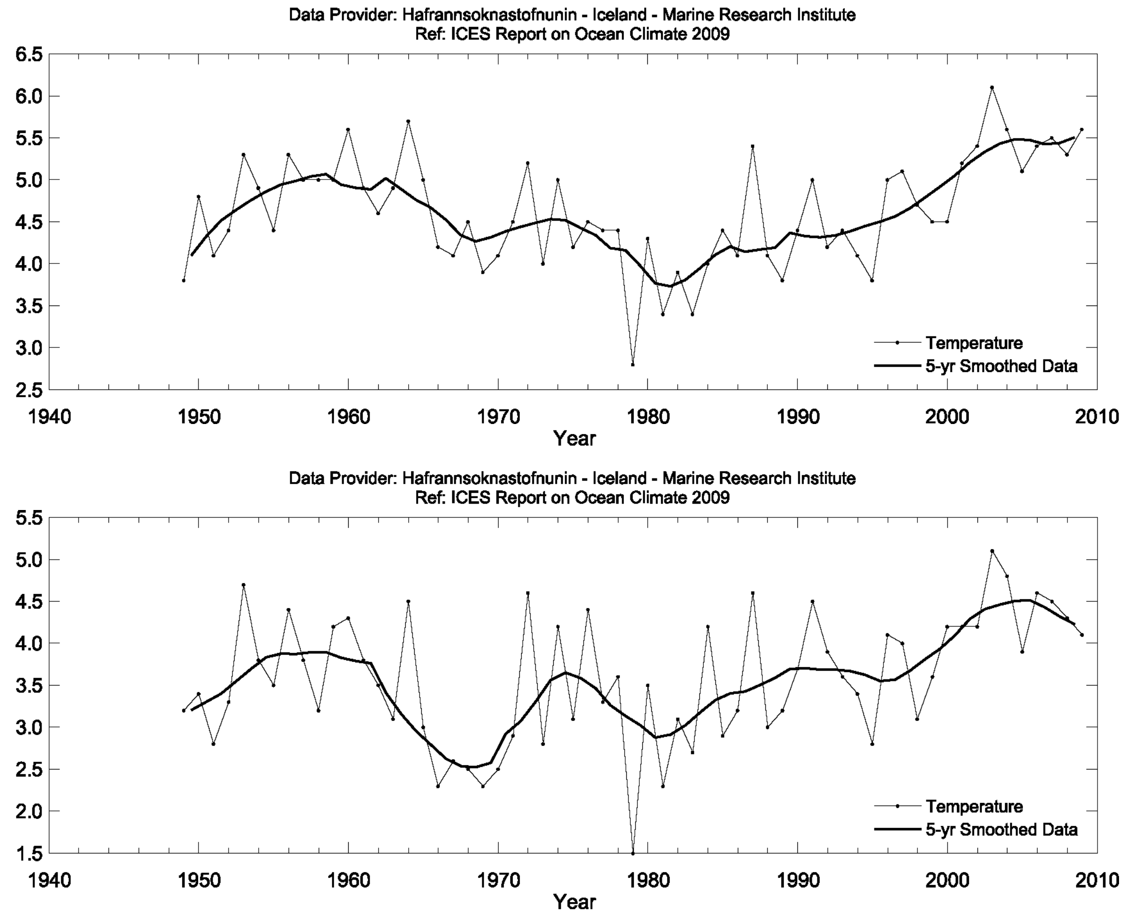


Figure 32.
Area 3 – Icelandic waters. Mean annual air temperature at Reykjavík (upper panel) and Akureyri (lower panel).

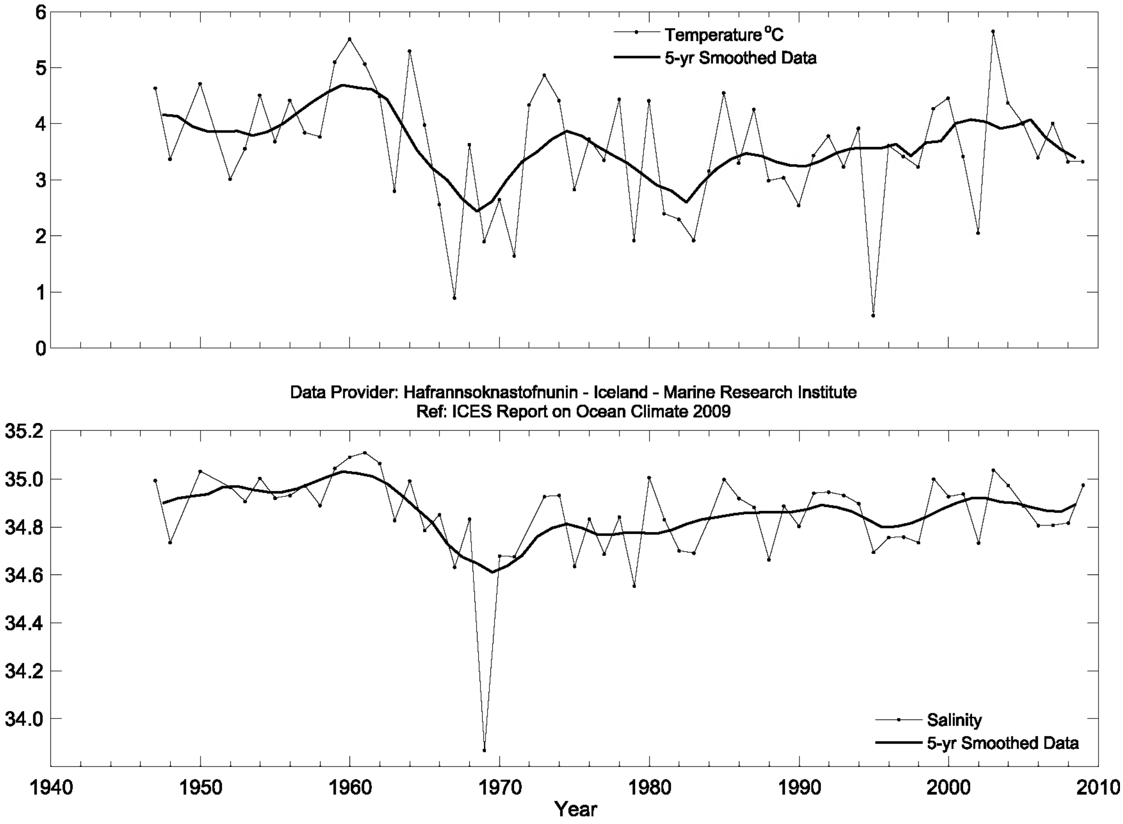


Figure 33.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 50–150 m at Siglunes Stations 2–4 in North Icelandic waters.

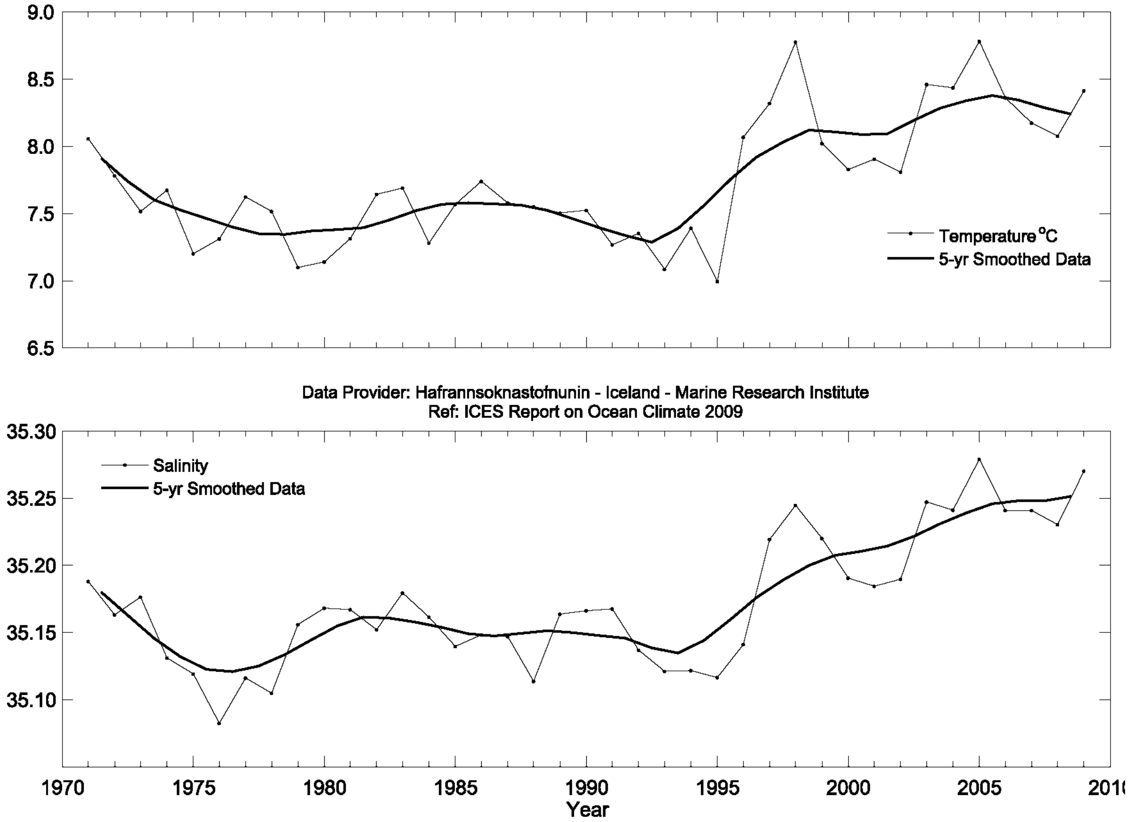


Figure 34.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 0–200 m at Selvogsbanki Station 5 in South Icelandic waters.

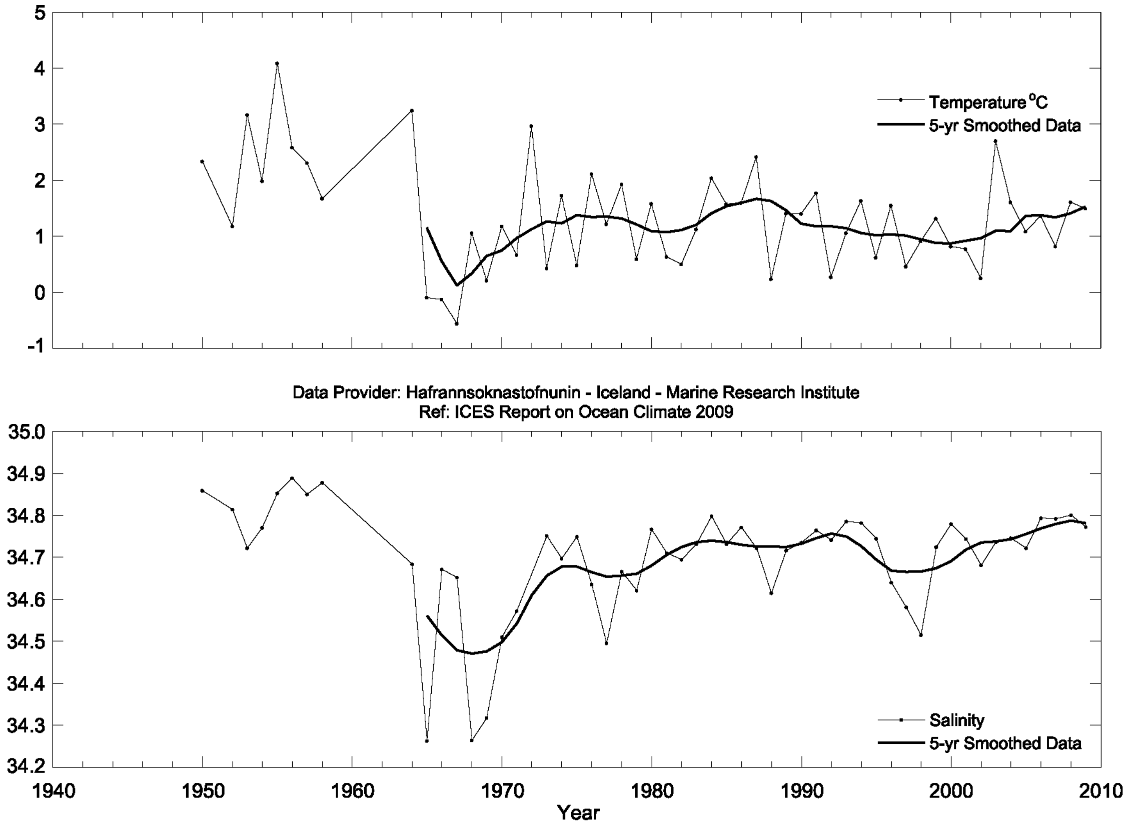


Figure 35.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 0–50 m in the East Icelandic Current (Langanes Stations 2–6).

4.7 Area 4 – Bay of Biscay and eastern North Atlantic

THE BAY OF BISCAY IS LOCATED IN THE EASTERN NORTH ATLANTIC. ITS GENERAL CIRCULATION FOLLOWS THE SUBTROPICAL ANTICYCLONIC GYRE AND IS RELATIVELY WEAK. IN THE SOUTHERN PART OF THE BAY OF BISCAY, EAST-FLOWING SHELF AND SLOPE CURRENTS RELATED TO THE IBERIAN POLEWARD CURRENT ARE COMMON IN AUTUMN AND WINTER AS A RESULT OF WESTERLY WINDS. IN SPRING AND SUMMER, EASTERLY WINDS ARE DOMINANT, AND COASTAL UPWELLING EVENTS ARE FREQUENT.

The year 2009 was one of contrasts in the Bay of Biscay; the whole year was close to average, but with a cold winter and early spring, and a warm late spring, summer, and autumn. Annual mean air temperature over the southern Bay of Biscay during 2009 was 0.38°C higher than the average value for the 1971–2000 period, but ca. 1°C lower than the warm years of 2003 and 2006. The 2009 pattern of cold winter and warm summer is similar to the pattern observed in 2005 and 2006, when large winter mixed-layer depths were recorded. As expected, the SST reflected the colder–warmer pattern, with high temperatures in June and July, in contrast to the cold winter and spring, and fast cooling from November to December. This pattern was driven by the fluctuations in air temperature and wind direction, related to the frequency of cloudy and rainy days and the subsequent reduction in solar radiation.

The pattern for subsurface and intermediate water differs from the air and SST pattern. The sequence of cold winters with deep mixed layers in 2005 and 2006, followed by an anomalous warm and shallow mixed layer in 2007, was reflected in shallow water masses, whereas at intermediate levels, a continued warming and increase in salinity was taking place. The cold period from autumn 2008 to early spring 2009 generated a winter mixed layer at ca. 250 m depth, which was colder and slightly less saline than in previous years. In addition, for the first time in the series, there was a slight cooling and freshening at the lower levels of central waters.

This area is occasionally affected by a strong high-salinity signal at the shelf and shelf break, a phenomenon typically associated with the advection of waters of subtropical origin through the Iberian Poleward Current (IPC). In 2008, the trend of increasing salinity that started in 2003 reached a maximum because of a strong IPC episode. However, in 2009, no IPC signal was observed, and the high rainfall and river run-off, combined with strong cooling and turbulent mixing in winter, reduced the salinity and heat content of the water column.

COLD TEMPERATURES AND STRONG FRESHWATER INPUT IN WINTER 2009 REDUCED UPPER OCEAN HEAT CONTENT AND SALINITY IN BISCAY AND THE EASTERN NORTH ATLANTIC.

CTD deployment. Image courtesy of Menchu Rodriguez, IEO, Spain.

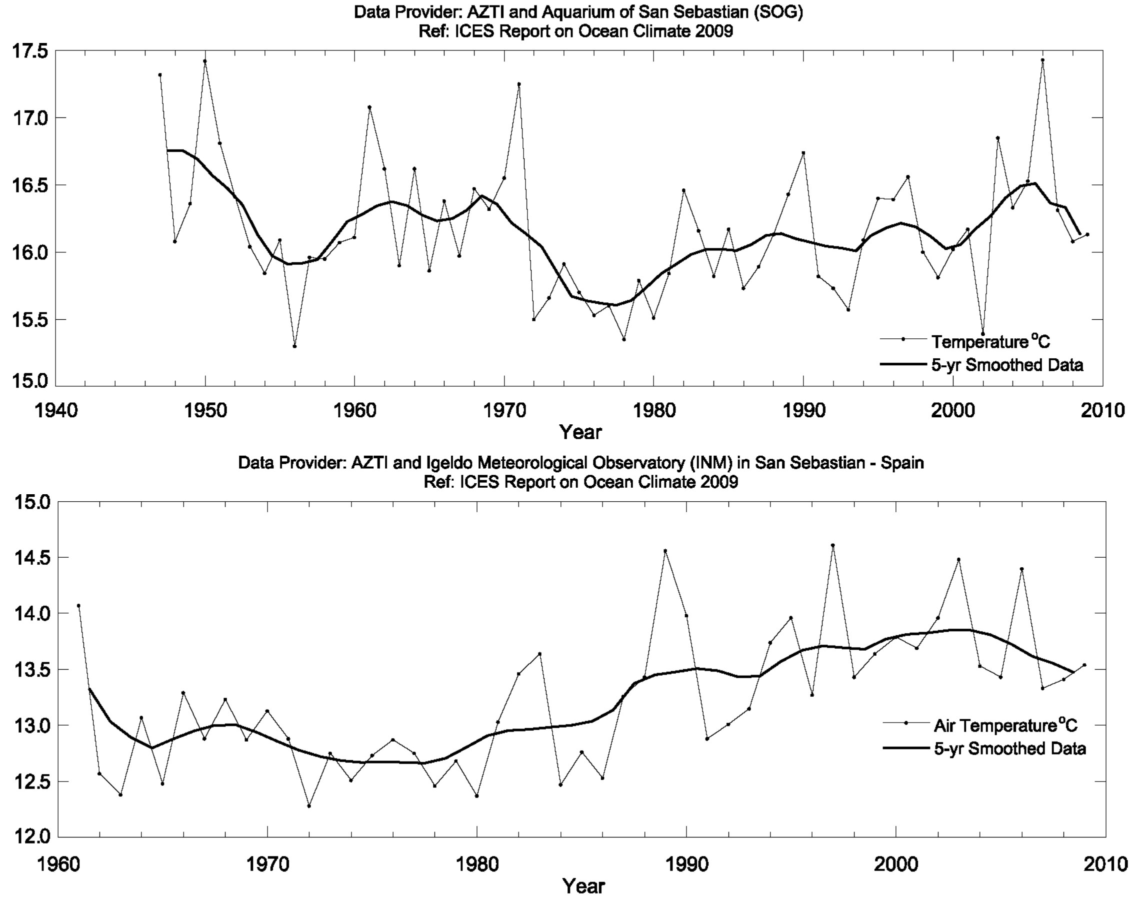


Figure 36 .
Area 4 – Bay of Biscay and eastern North Atlantic. Sea surface temperature (upper panel) and air temperature (lower panel) at San Sebastian (43°18.5'N 02°2.37'W).

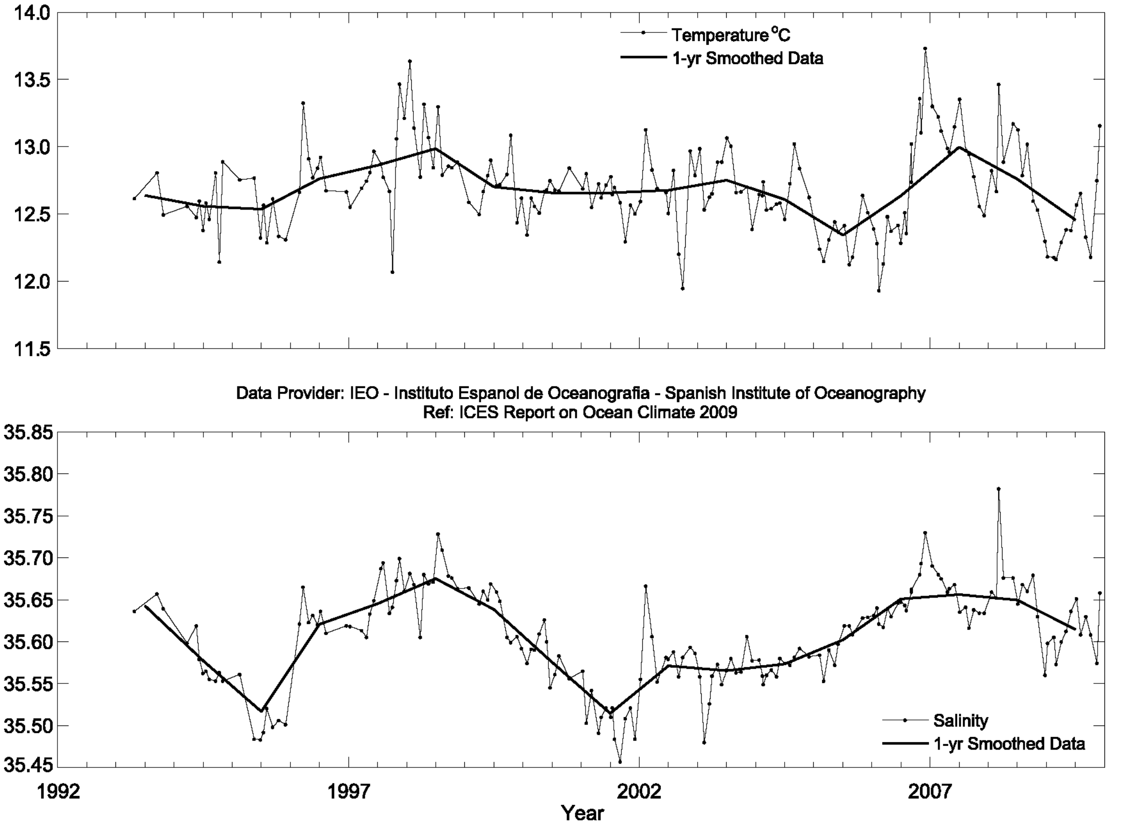


Figure 37 .
Area 4 – Bay of Biscay and eastern North Atlantic. Potential temperature (upper panel) and salinity (lower panel) at Santander Station 6 (5–300 m).

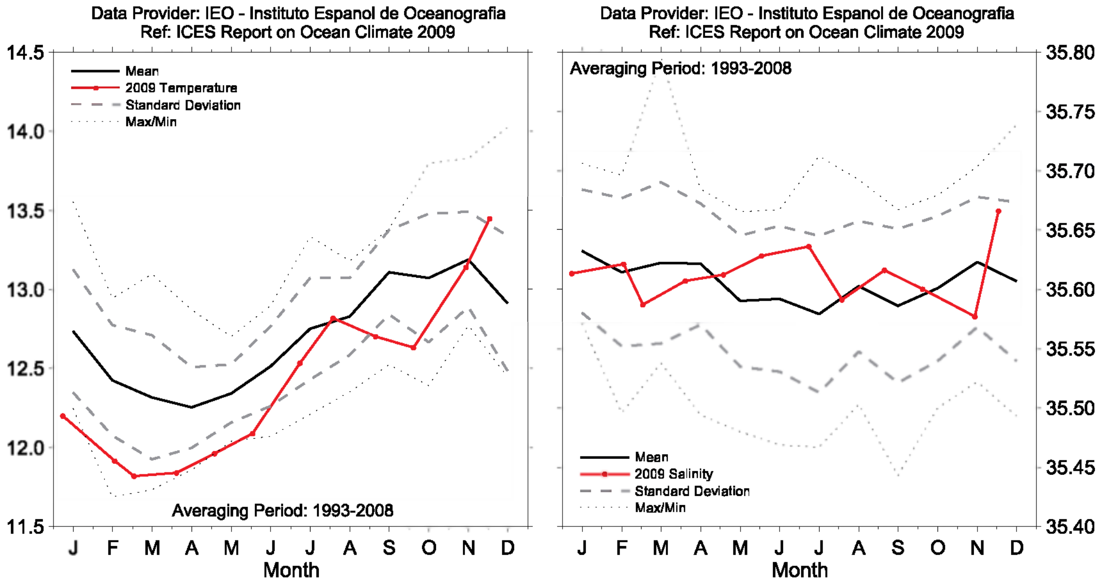


Figure 38.
Area 4 - Bay of Biscay and eastern North Atlantic. 2009 monthly temperature (left panel) and salinity (right panel) at Santander Station 6 (5–300 m).

4.8 Area 4b – Northwest European continental shelf

Western English Channel

Station E1 (50.03°N 4.37°W) is situated in the western English Channel and is mainly influenced by North Atlantic water. The water depth is 75 m, and the station is tidally influenced by a 1.1 knot maximum surface stream at mean spring tide. The seabed is mainly sand, resulting in a low bottom stress (1–2 ergs cm^{-2} s^{-1}). The station may be described as oceanic with the development of a seasonal thermocline; stratification typically starts in early April, persists throughout summer, and is eroded by the end of October. The typical depth of the summer thermocline is around 20 m. The station is greatly affected by ambient weather.

Measurements have been taken at this station since the end of the 19th century, with data currently available since 1903. The series is unbroken, apart from the gaps for the two world wars and a hiatus in funding between 1985 and 2002. The data takes the form of vertical profiles of temperature and salinity. Early measurements were taken with reversing mercury-in-glass thermometers and discrete salinity bottles. More recently, electronic equipment (Seabird CTD) has been utilized.

The time-series demonstrates considerable interannual variability in temperature. In 2009, Station E1 was sampled on 15 occasions, with no sampling occurring during August and November. The minimum recorded surface temperature (February) was 9.1°C, and the maximum surface temperature (September) was 16.4°C. The temperatures for the year as a whole were close to average throughout, although slightly cooler than the long-term mean in spring and early summer (as in 2008). The autumn period was particularly warm, with temperatures greater than 2 standard deviations above the mean.

AVERAGE TEMPERATURE FOR MOST OF THE YEAR, BUT A VERY WARM AUTUMN IN THE WESTERN ENGLISH CHANNEL.

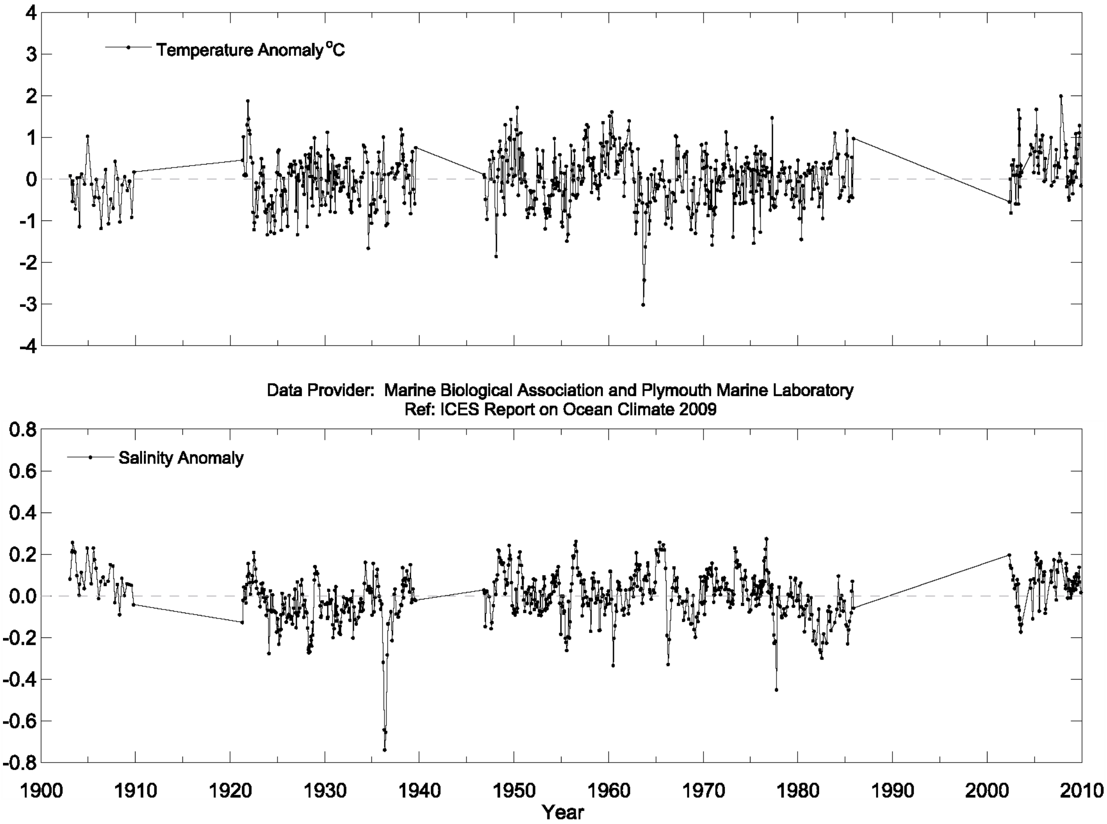


Figure 39.
Area 4b – Northwest European continental shelf. Temperature anomalies (upper panel) and salinity anomalies (lower panel) of surface water at Station E1 in the western English Channel (50.03°N 4.37°W).

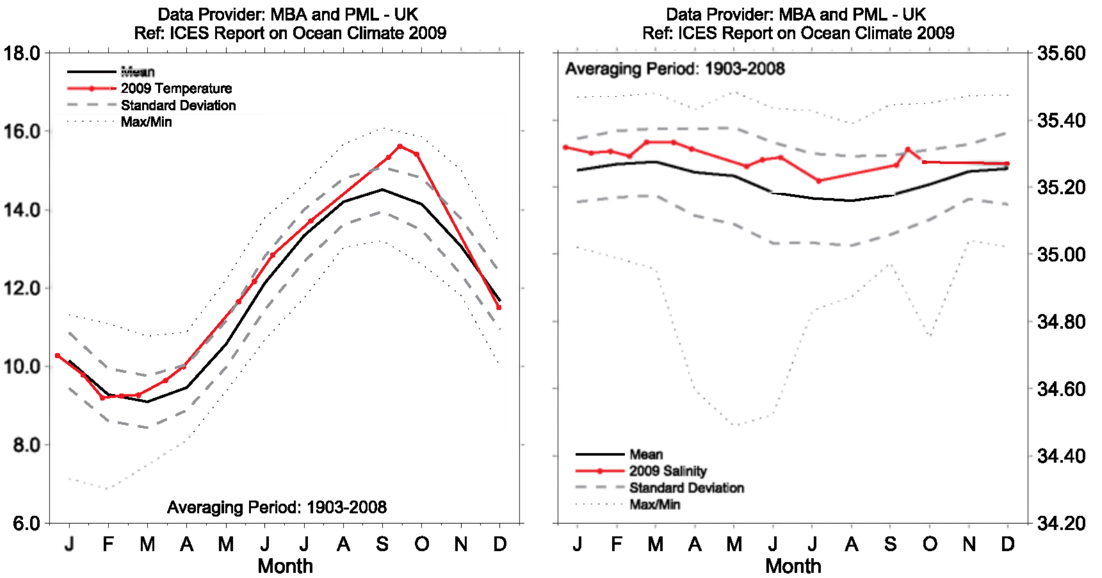


Figure 40.
Area 4b – Northwest European continental shelf. 2009 monthly temperature (left panel) and salinity (right panel) of surface water at Station E1 in the western English Channel (50.03°N 4.37°W).

North and southwest of Ireland

THE TIME-SERIES OF SURFACE OBSERVATIONS AT THE MALIN HEAD COASTAL STATION (THE MOST NORTHERLY POINT OF IRELAND) IS INSHORE OF COASTAL CURRENTS AND INFLUENCED BY RUN-OFF. AN OFFSHORE WEATHER BUOY HAS BEEN MAINTAINED AT 51.22°N 10.55°W OFF THE SOUTHWEST COAST OF IRELAND SINCE MID-2002, WHERE SEA SURFACE TEMPERATURE DATA ARE MEASURED HOURLY.

At Malin Head, sea surface temperatures have been increasing since the late 1980s, and those for the mid-2000s were the highest since records began in 1960. No data are available for 2009.

At the M3 buoy, there is considerable interannual variability, with the warmest recorded summer temperatures in 2003 and 2005, and the warmest winter temperatures in 2007. In 2009, temperatures were below the time-series mean (2003–2009) until autumn, when they rose until they were similar to the time-series mean for the remainder of the year.

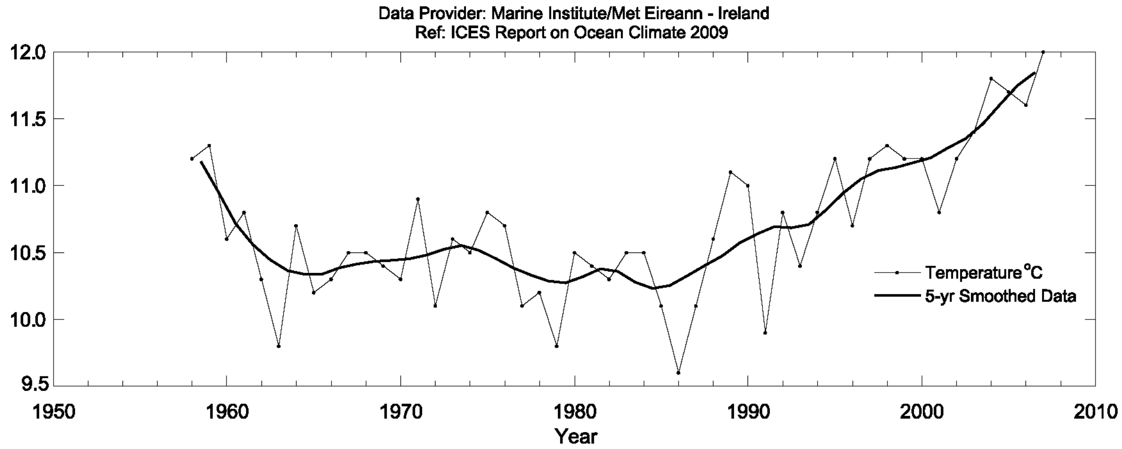


Figure 41.
Area 4b – Northwest European continental shelf. Temperature at the Malin Head coastal station (55.39°N 7.38°W).

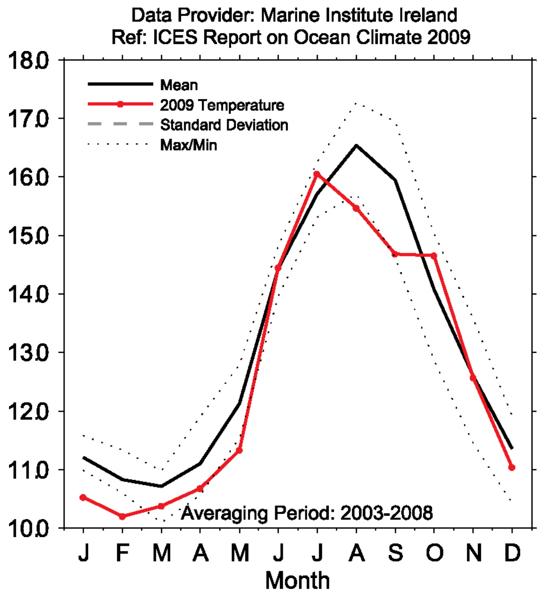


Figure 42.
Area 4b – Northwest European continental shelf. 2008 monthly temperature at the M3 Weather Buoy southwest of Ireland (51.22°N 10.55°W). No salinity data collected at this station.

4.9 Area 5 – Rockall Trough

THE ROCKALL TROUGH IS SITUATED WEST OF BRITAIN AND IRELAND AND IS SEPARATED FROM THE ICELAND BASIN BY HATTON AND ROCKALL BANKS, AND FROM THE NORDIC SEAS BY THE SHALLOW (500 M) WYVILLE–THOMSON RIDGE. IT ALLOWS WARM NORTH ATLANTIC UPPER WATER TO REACH THE NORWEGIAN SEA, WHERE IT IS CONVERTED INTO COLD, DENSE OVERFLOW WATER AS PART OF THE THERMOHALINE OVERTURNING IN THE NORTH ATLANTIC. THE UPPER WATER COLUMN IS CHARACTERIZED BY POLEWARD-MOVING EASTERN NORTH ATLANTIC WATER, WHICH IS WARMER AND SALTIER THAN WATERS OF THE ICELAND BASIN, WHICH ALSO CONTRIBUTE TO THE NORDIC SEA INFLOW.

The latest measurements in the Rockall Trough were made in June 2009. Both temperature and salinity of the upper 800 m between Rockall and the Hebridean continental shelf remained higher than the long-term mean. Temperature peaked in October 2006 and has demonstrated a decrease of ca. 0.3°C since then. Conversely, salinity has remained high, with measurements in 2008 and 2009 matching the previous all-time high seen in 2003. However, such variability is not considered significant in the long-term trend.

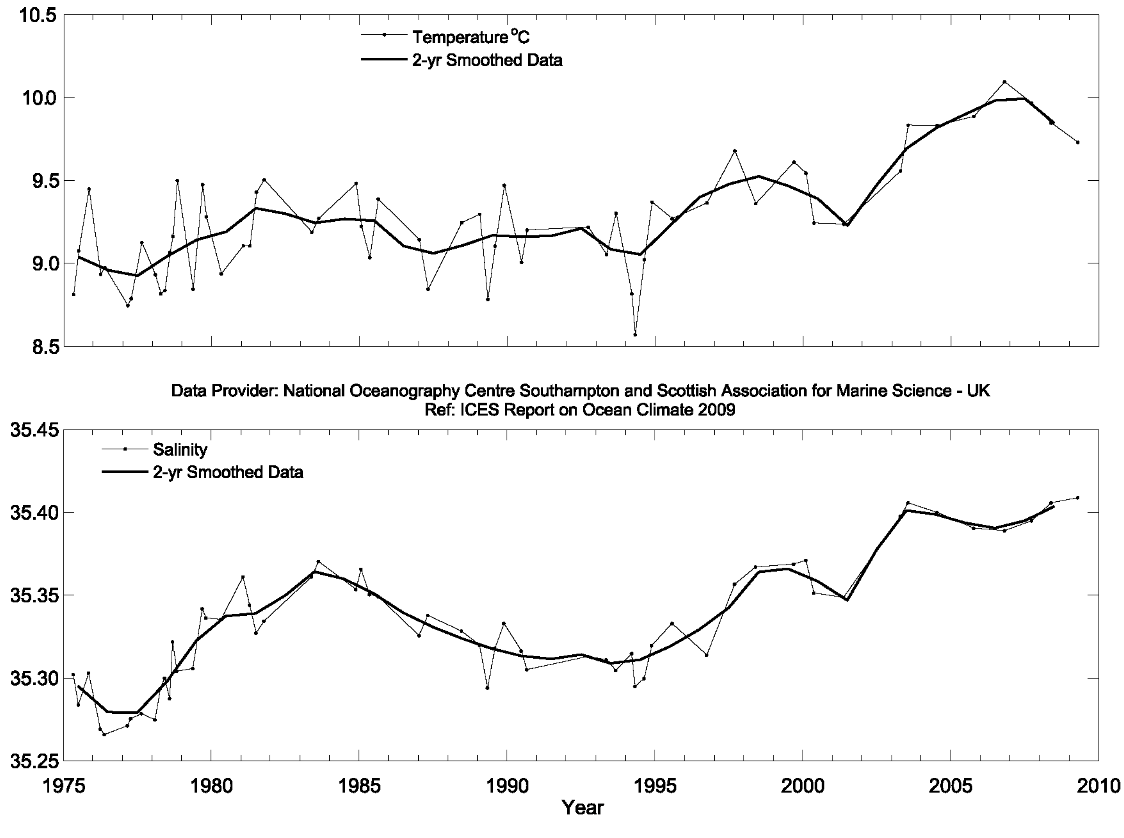


Figure 43.
Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) for the upper ocean (0–800 m).

TEMPERATURE AND SALINITY REMAIN HIGH IN 2009 IN THE ROCKALL TROUGH.

4.10 Area 5b – Irminger Sea

THE IRMINGER SEA IS THE OCEAN BASIN BETWEEN SOUTHERN GREENLAND, THE REYKJANES RIDGE, AND ICELAND. THIS AREA FORMS PART OF THE NORTH ATLANTIC SUBARCTIC ANTICYCLONIC GYRE. AS A RESULT OF THIS GYRE, THE EXCHANGE OF WATER BETWEEN THE IRMINGER SEA AND THE LABRADOR SEA IS RELATIVELY FAST. THE IRMINGER SEA IS INFLUENCED BY WARM SALINE WATER COMING FROM THE ICELAND BASIN, WHICH REACHES THE NORTHERN BASIN FIRST.

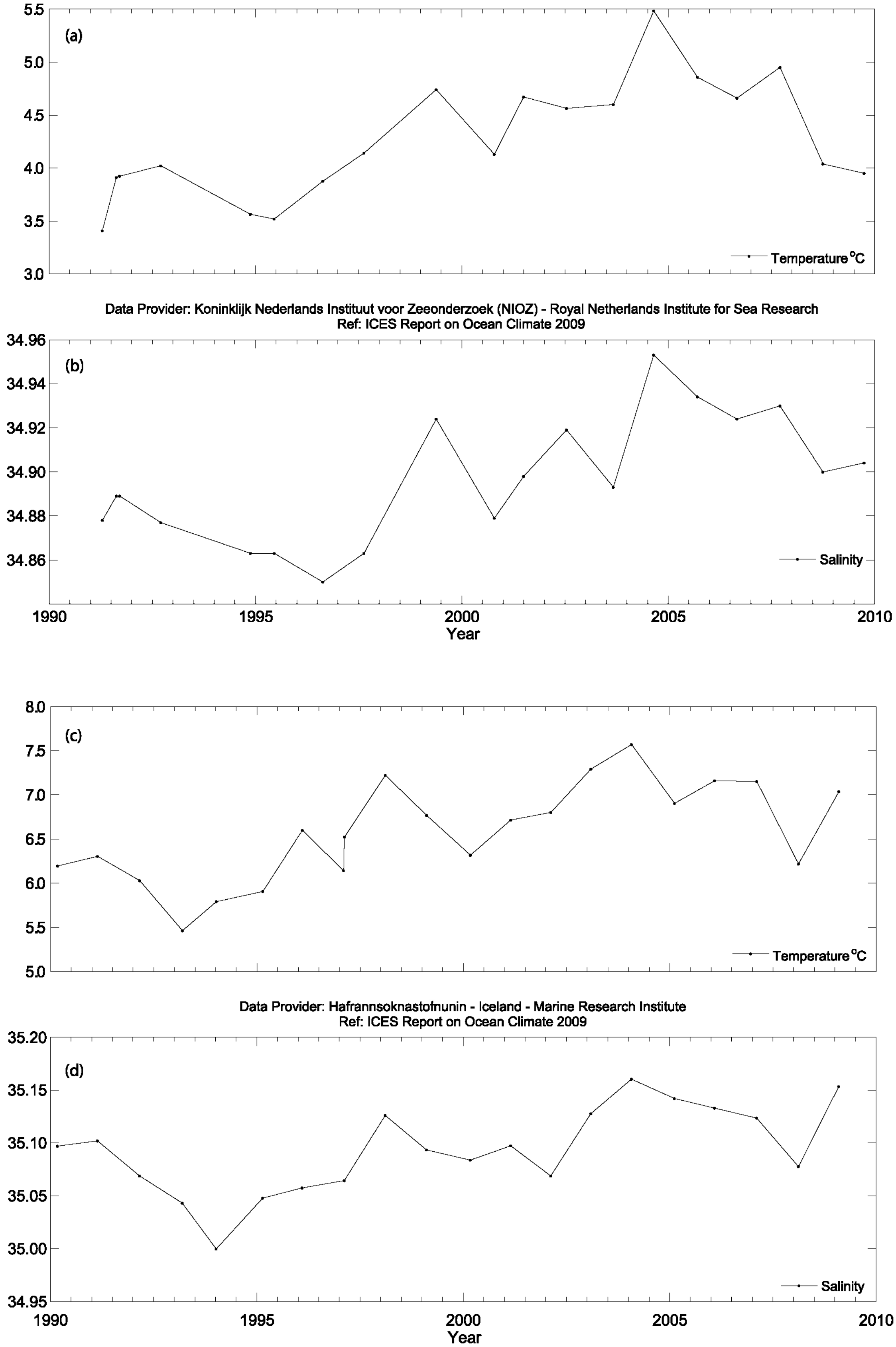
In 2004, the Subpolar Mode Water (SPMW) in the centre of the Irminger Sea, in the pressure interval 200–400 dbar, reached its highest temperature and salinity since 1991. Since then, a slight cooling and freshening has occurred, related to a lack of convective activity. In winter 2007/2008, convection in the SPMW reached depths of at least 1000 m, resulting in a temperature decrease of nearly 1°C and a salinity decrease of 0.03 from 2007 to 2008, similar to the SPMW change observed after the cold winter of 1999/2000. In 2009, the cooling trend of the SPMW continued, with a decrease of nearly 0.1°C. The salinity in 2009 increased by 0.004 relative to 2008 observations, but the decreasing trend since 2004 is still significant.

In the northern Irminger Sea, however, the SPMW (200–500 m) demonstrated a large rise in temperature and salinity in 2009, reversing the cooling-freshening trend between 2004 and 2008. In addition, the 0–200 m surface layer demonstrated a record-high salinity in 2009 and early 2010.

COOLING AND FRESHENING SINCE 2004 IN THE CENTRAL IRMINGER SEA, BUT HIGHER SALINITY IN THE NORTH.

Deployment of Seabird CTD from FRV Alba na Mara. Image courtesy of Marine Scotland, Aberdeen UK.

Figure 44.
Area 5b – Irminger Sea. Temperature (panel a) and salinity (panel b) of Subpolar Mode Water in the central Irminger Sea (averaged over 200–400 m), and temperature (panel c) and salinity (panel d) of Subpolar Mode Water in the northern Irminger Sea (Station FX9, 64°20′N 28°0′W, averaged over 200– 500 m).



4.11 Area 6 – Faroe Bank Channel and Faroe Current

ONE BRANCH OF THE NORTH ATLANTIC CURRENT CROSSES THE GREENLAND–SCOTLAND RIDGE ON BOTH SIDES OF THE FAROES. ITS PROPERTIES ARE SAMPLED BY THE FAROE BANK CHANNEL BEFORE IT CROSSES THE RIDGE, AND BY THE FAROE CURRENT AFTER IT CROSSES THE RIDGE.

Temperature and salinity of the upper waters in the Faroe region have generally increased since the mid-1990s. Salinities increased from 2008 to 2009, reaching a record high in November 2009, whereas temperatures were similar to those in the early 2000s. Conditions still remain exceptionally warm and saline in the century-long perspective given by the Faroe coastal temperature time-series, although, like all coastal and shelf time-series, this is affected by atmospheric and terrestrial effects. In 2009, the annual average Faroe coastal temperature was equal to the record-high temperature in 2003.

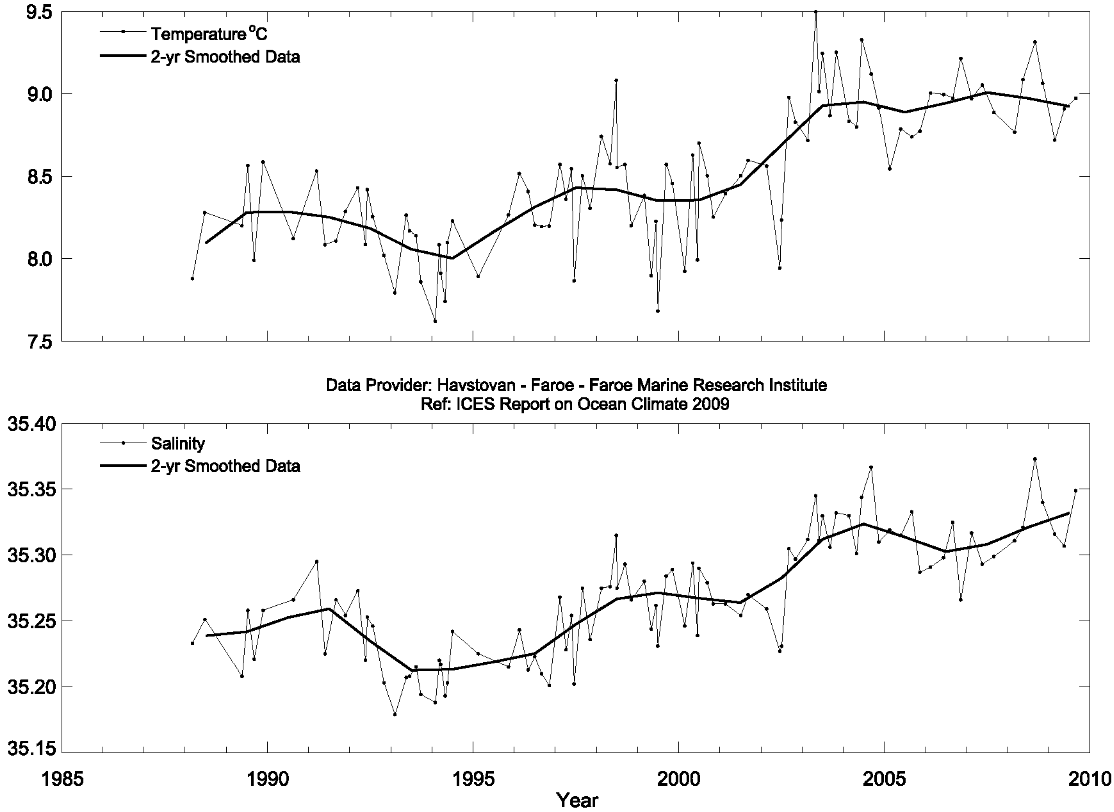


Figure 45.
Area 6 – Faroe Bank Channel and Faroe Current Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Atlantic Water in the Slope Current.

IN 2009, RECORD-HIGH VALUES OF BOTH TEMPERATURE AND SALINITY OBSERVED IN MODIFIED NORTH ATLANTIC WATER.

Figure 46.
Area 6 – Faroe Bank Channel and Faroe Current. Temperature (upper panel) and salinity (lower panel) in the core of the Faroe Current (maximum salinity averaged over a 50 m deep layer).

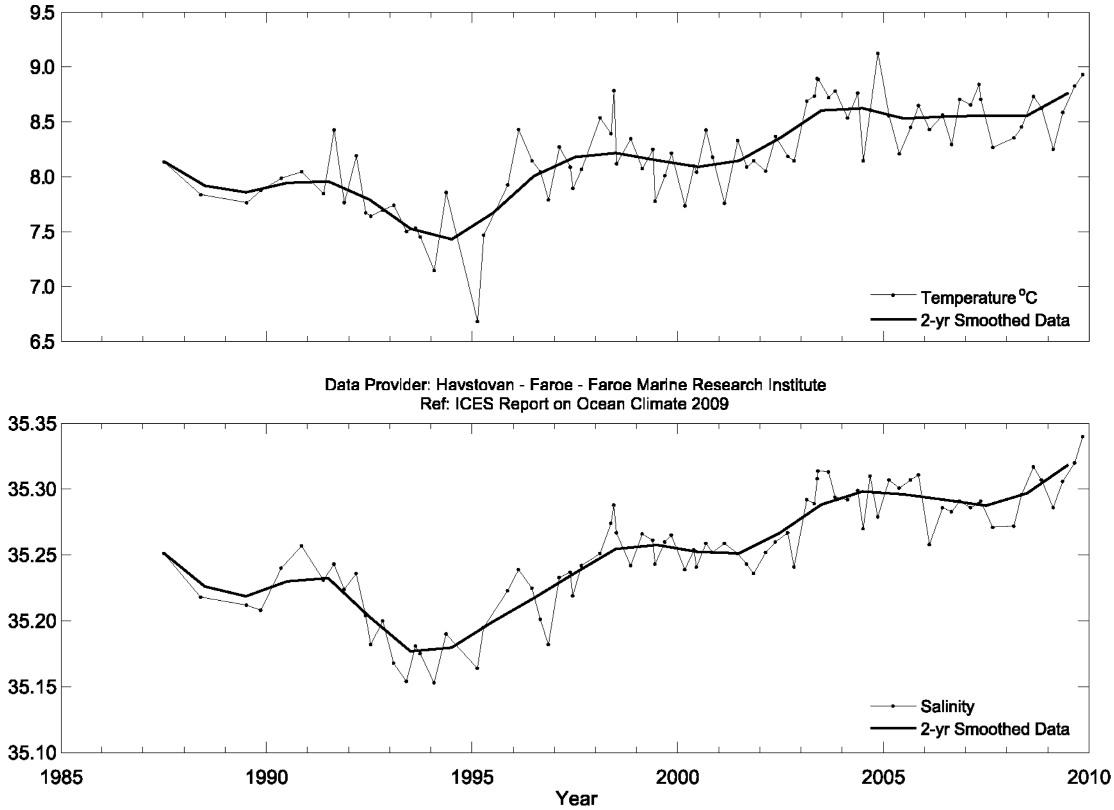
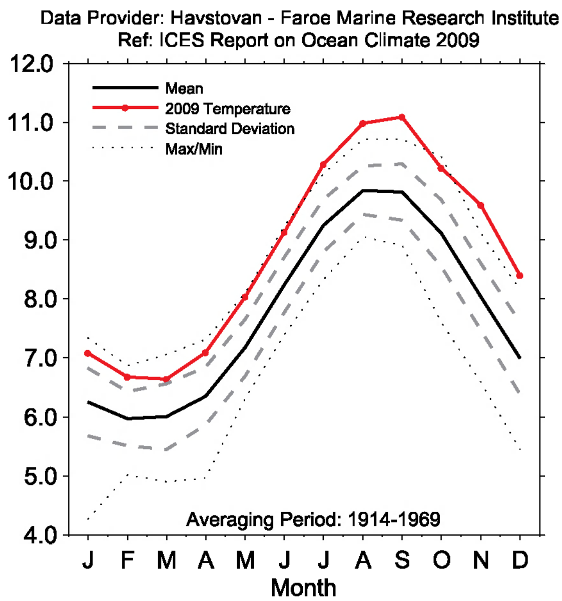


Figure 47.
Area 6 – Faroe Bank Channel and Faroe Current. 2009 monthly temperature data from the Faroe coastal station at Oyrargjogv (62.12°N 7.17°W). Note the average values were calculated from the nearby station at Mykines (69.10°N 7.66°W).



4.12 Area 7 – Faroe–Shetland Channel

THE CONTINENTAL SLOPE CURRENT FLOWS ALONG THE EDGE OF THE NORTHWEST EUROPEAN CONTINENTAL SHELF; ORIGINATING IN THE SOUTHERN ROCKALL TROUGH. IT CARRIES WARM, SALINE ATLANTIC WATER (AW) INTO THE FAROE–SHETLAND CHANNEL. A PROPORTION OF THIS AW CROSSES ONTO THE SHELF ITSELF AND ENTERS THE NORTH SEA, WHERE IT IS DILUTED WITH COASTAL WATER AND EVENTUALLY LEAVES IN THE NORWEGIAN COASTAL CURRENT. THE REMAINDER ENTERS THE NORWEGIAN SEA TO BECOME THE NORWEGIAN AW. MODIFIED NORTH ATLANTIC WATER ENTERS THE FAROE-SHETLAND CHANNEL FROM THE NORTH AFTER CIRCULATING AROUND THE FAROE ISLANDS. THIS SECOND BRANCH OF AW JOINS THE WATERS ORIGINATING IN THE SLOPE CURRENT AND ALSO ENTERS THE NORWEGIAN SEA.

The temperature and salinity of the surface waters of the Faroe–Shetland Channel have generally increased over the past two decades. The water on the western slopes of the Channel, known as modified North Atlantic Water, reached record-high levels of temperature and salinity in 2009.This water is thought to have passed into the Faroe–Shetland Channel from north of Faroe. On the eastern side of the Faroe–Shetland Channel, both salinity and temperature remained high, although they have declined slightly since the record-high salinities observed in 2003/2004.

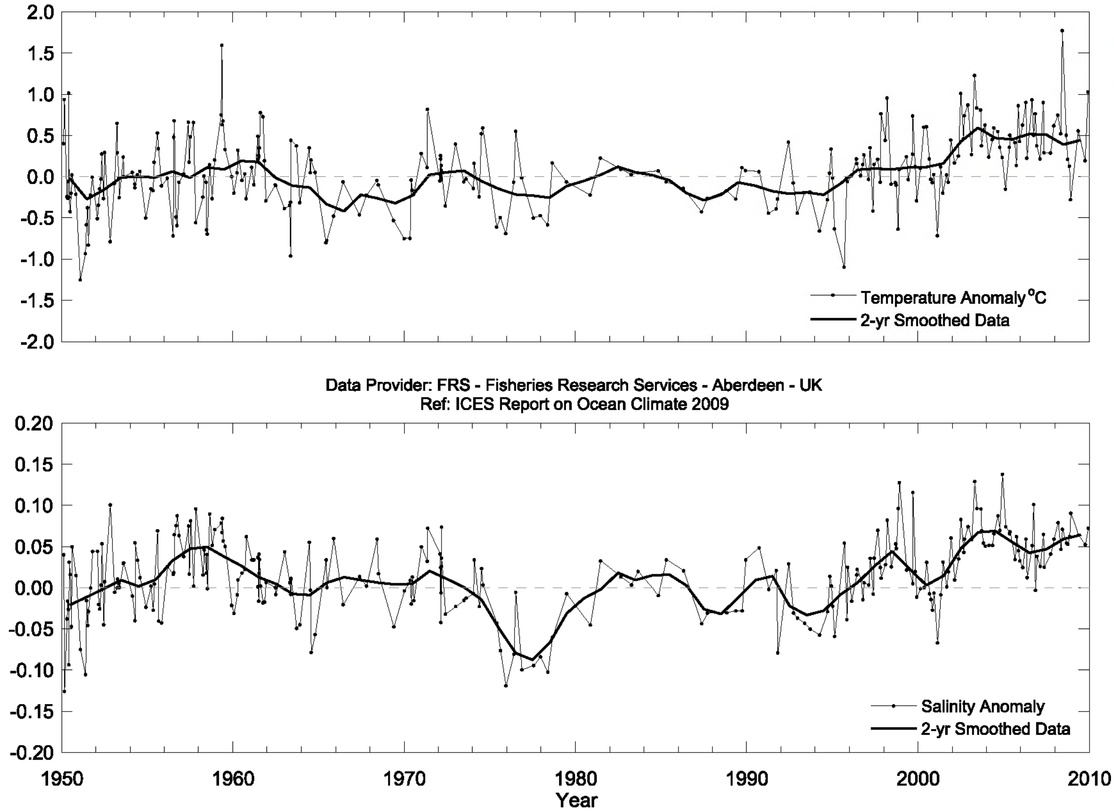


Figure 48.
Area 7 – Faroe–Shetland Channel. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Atlantic Water in the Slope Current.

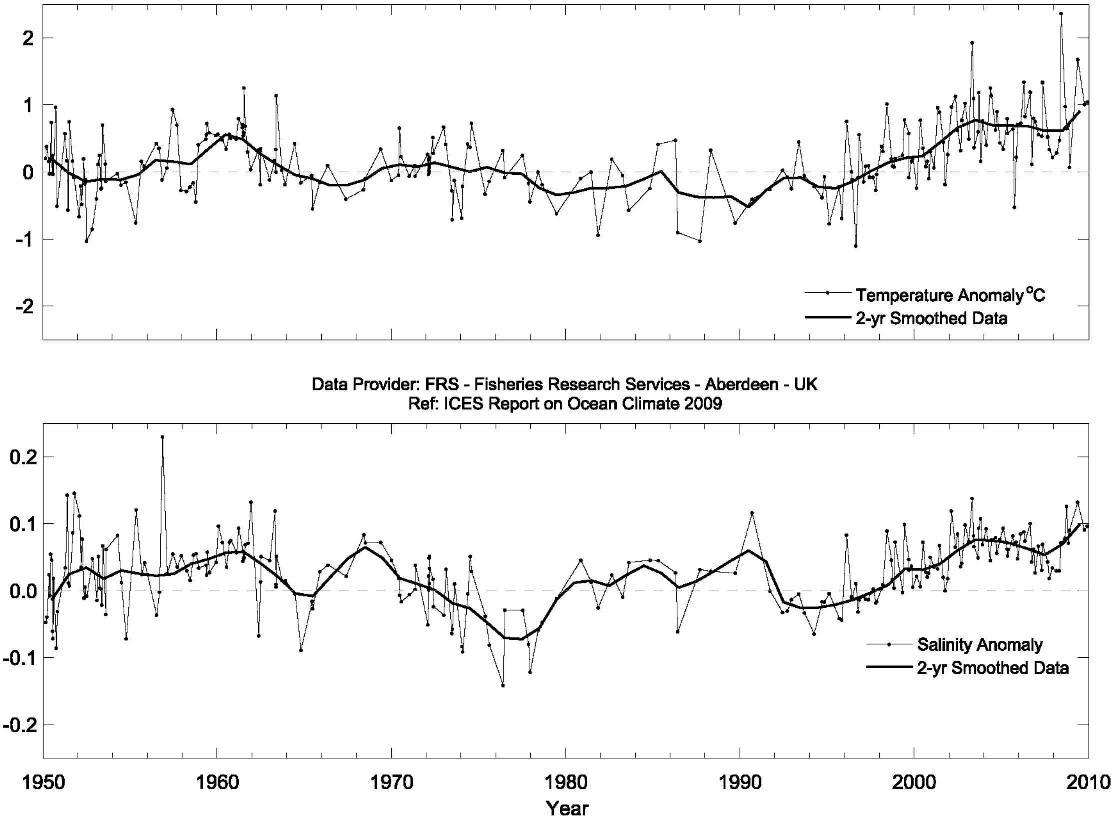


Figure 49.
Area 7 – Faroe–Shetland Channel. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Modified Atlantic Water entering the Faroe–Shetland Channel from the north after circulating around the Faroes.

4.13 Areas 8 and 9 – Northern and southern North Sea

NORTH SEA OCEANOGRAPHIC CONDITIONS ARE DETERMINED BY THE INFLOW OF SALINE ATLANTIC WATER (AW) AND THE OCEAN–ATMOSPHERE HEAT EXCHANGE. THE INFLOW THROUGH THE NORTHERN ENTRANCES (AND, TO A LESSER DEGREE, THROUGH THE ENGLISH CHANNEL) CAN BE STRONGLY INFLUENCED BY THE NAO. NUMERICAL MODEL SIMULATIONS ALSO DEMONSTRATE STRONG DIFFERENCES IN THE NORTH SEA CIRCULATION, DEPENDING ON THE STATE OF THE NAO. THE AW MIXES WITH RIVER RUN-OFF AND LOWER SALINITY BALTIC OUTFLOW ALONG THE NORWEGIAN COAST. A BALANCE OF TIDAL MIXING AND LOCAL HEATING FORCES THE DEVELOPMENT OF A SEASONAL STRATIFICATION FROM APRIL/MAY TO SEPTEMBER IN MOST PARTS OF THE NORTH SEA.

During the first half of 2009, the weekly means of area-averaged SST were close to the long-term values, i.e. there was no excess heat from the previous year. The monthly temperature anomalies between January and June varied between –0.1 and +0.9°C. Between June and July, there was a pronounced warming, and the monthly temperature anomaly increased from 0.8 to 1.6°C and varied between 0.8 and 1.3°C for the last five months. The annual temperature anomaly was 0.8°C. Besides the inflow of warmer Atlantic Water (AW) at the northern boundary and through the English Channel, much of the SST variability is caused by the local ocean–atmosphere heat flux.

In contrast to 2008, the near-surface temperature in 2009 again exhibits the typical gradient, with increasing temperatures from the open northern boundary towards the inner German Bight and with isotherms running approximately from southwest

THE REMAINDER ENTERS THE NORWEGIAN SEA TO BECOME THE NORWEGIAN AW. MODIFIED NORTH ATLANTIC WATER ENTERS THE FAROE-SHETLAND CHANNEL FROM THE NORTH to northeast. The bottom distribution is comparable with 2008. The vertically mixed areas along the southern Danish coast are warmer than in 2008, with temperatures close to 20°C. The thermocline depth of the stratified central North Sea and Skagerrak area exceeds 40 m, with maximum gradients of ca. 3°C m^{-1}. The sharpness of the thermocline is gradually decreasing north of 57°N. The local depression of the thermocline at ca. 7°E along the 58°N section, which was observed in 9 of 12 years, shows a record depth of ca. 80 m.

The bottom layer is generally thinner and warmer than in 2008; however, the 2009 cruise was carried out one month later than in previous surveys, and the bottom layer is generally expected to reach its temperature maximum approximately one month later than the surface layer. The 54°N section was completely vertically mixed as a result of tidal mixing, whereas the 55°N section was vertically mixed at its eastern section and above Dogger Bank, but stratified east of 1.5°E.

Compared with 2008, the salinity concentrations in the surface and bottom layers increased in the northern part of the North Sea. The tongue of AW with salinity >35 in the near-surface layer extended nearly 2 degrees farther south and ca. 4 degrees farther east. Also, in the outflow region of the English Channel, small lenses with salinity >35 were detected in both layers. Generally, the influence of the Channel is greater than in previous years. The ribbon of low-salinity water in the surface layer along the Norwegian coast, with salinity <34, is smaller than in 2008, but broader in both layers along the Dutch, German, and Danish coasts. Therefore, the total salt content decreased a little from 2008. At 56°N, between 3°E and 5.5°E, there is a block of warm, high-salinity water overlying colder, low-salinity water, which is very unusual. The 57°N section demonstrates vertical columns or intrusions of high-salinity water between the surface and bottom layers. This might be caused by the strong and rapidly changing winds during the cruise. The total salt content during the 2009 survey was 1.140×10^{12} t, which is very close to the 2000–2009 average of 1.142×10^{12} t.

NEAR-NORMAL TEMPERATURE AND HIGH SALINITY IN THE NORTH SEA.

Between January and February, the monthly Elbe River run-off was ca. 1 standard deviation below the long-term mean whereas, during March, it was ca. 1.5 standard deviations above it. The annual averaged run-off was ca. 20 km^3 $year^{-1}$, which is slightly below the long-term mean.

Temperature and salinity at two positions in the northern North Sea illustrate conditions in the Atlantic inflow (Figure 51). The first (Location A) is at the near-bottom in the northwestern part of the North Sea, and the second (Location B) is in the core of the AW at the western shelf edge of the Norwegian Trench. Measurements were taken during summer and represent the previous winter's conditions. The average temperature at Location A was 1–2°C lower than at Location B, and salinity was also slightly lower. In both locations, there were above-average temperatures and salinities in 2009, and there has been an increase in both salinities and temperatures from 2008.

Effects on the ecosystem dynamics in the North Sea and the Skagerrak.

- In the Skagerrak, in addition to overall increased temperature, the length of the warm season has increased significantly over the last few years (conditions in the Skagerrak are thought to be representative of conditions throughout the North Sea). This is unlike most of the past 45 years, although similar conditions were observed around 1990. The result is that cold water, previously observed during large parts of the year, has now been absent for several years. Together with the high temperatures, this will have significant effects on ecosystem dynamics in the North Sea and the Skagerrak.

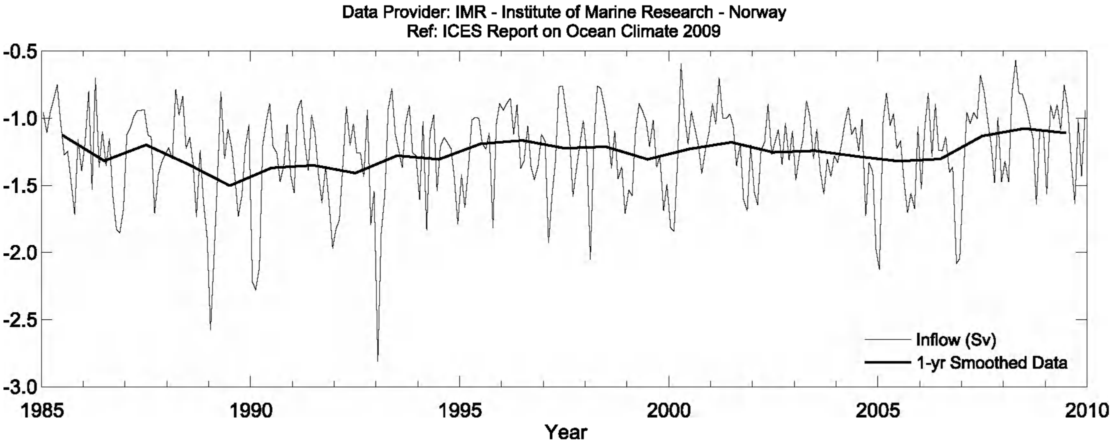


Figure 50.
Area 8 – Northern North Sea. Modelled annual mean (bold) and monthly mean volume transport of Atlantic Water into the northern and central North Sea southwards between the Orkney Islands and Utsire, Norway.

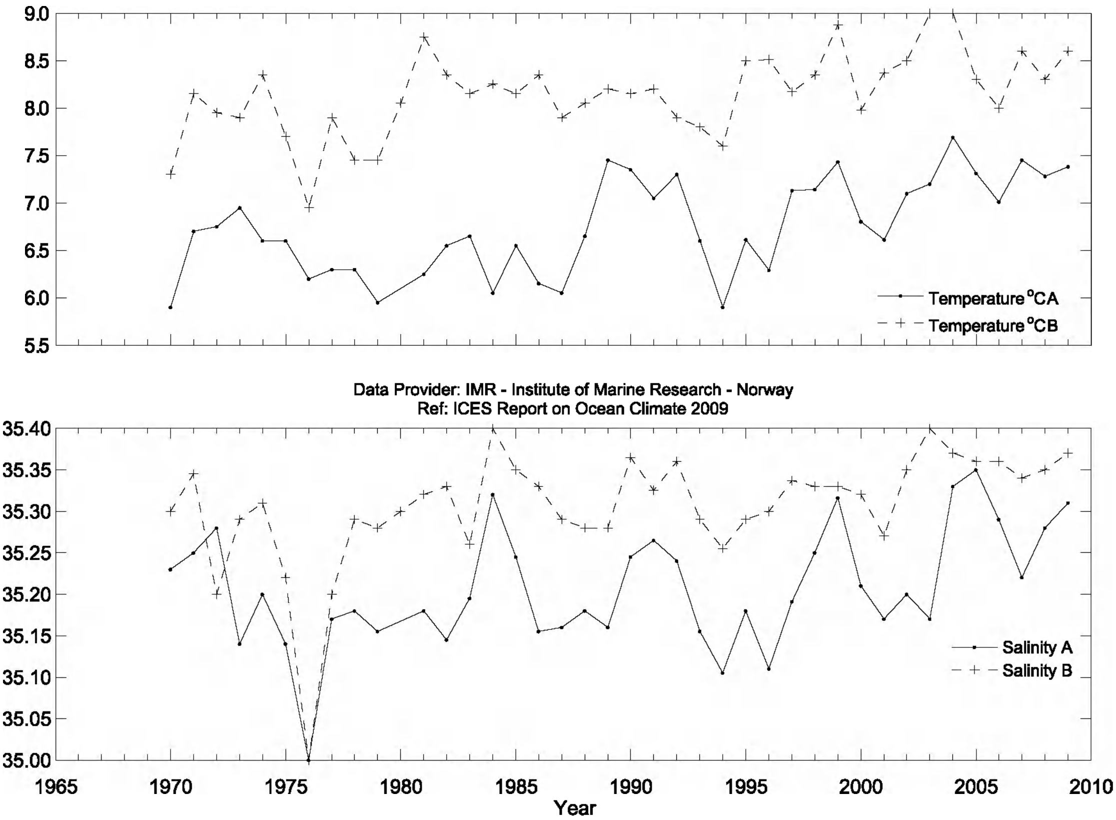


Figure 51.
Area 8 – Northern North Sea. Temperature (upper panel) and salinity (lower panel) near the seabed in the northwestern part of the North Sea (Location A) and in the core of Atlantic Water at the western shelf edge of the Norwegian Trench (Location B) during summer.

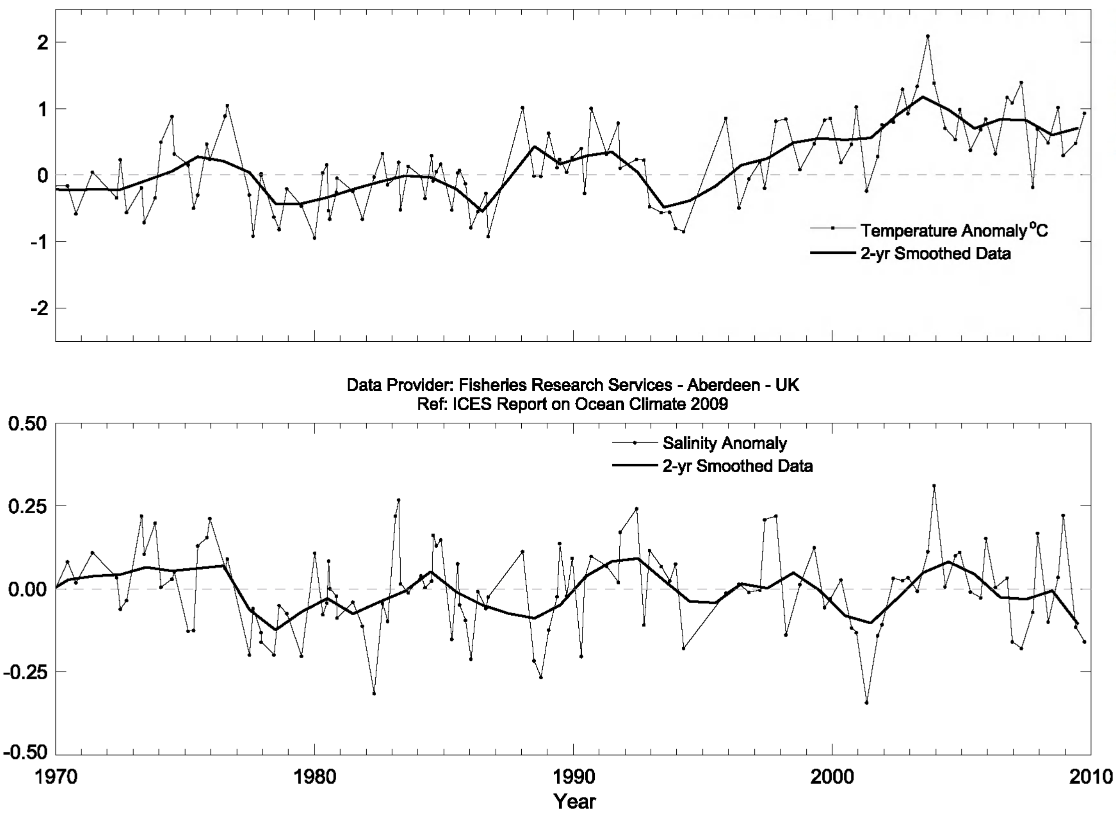


Figure 52.
Area 8 – Northern North Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Fair Isle Current entering the North Sea from the North Atlantic.

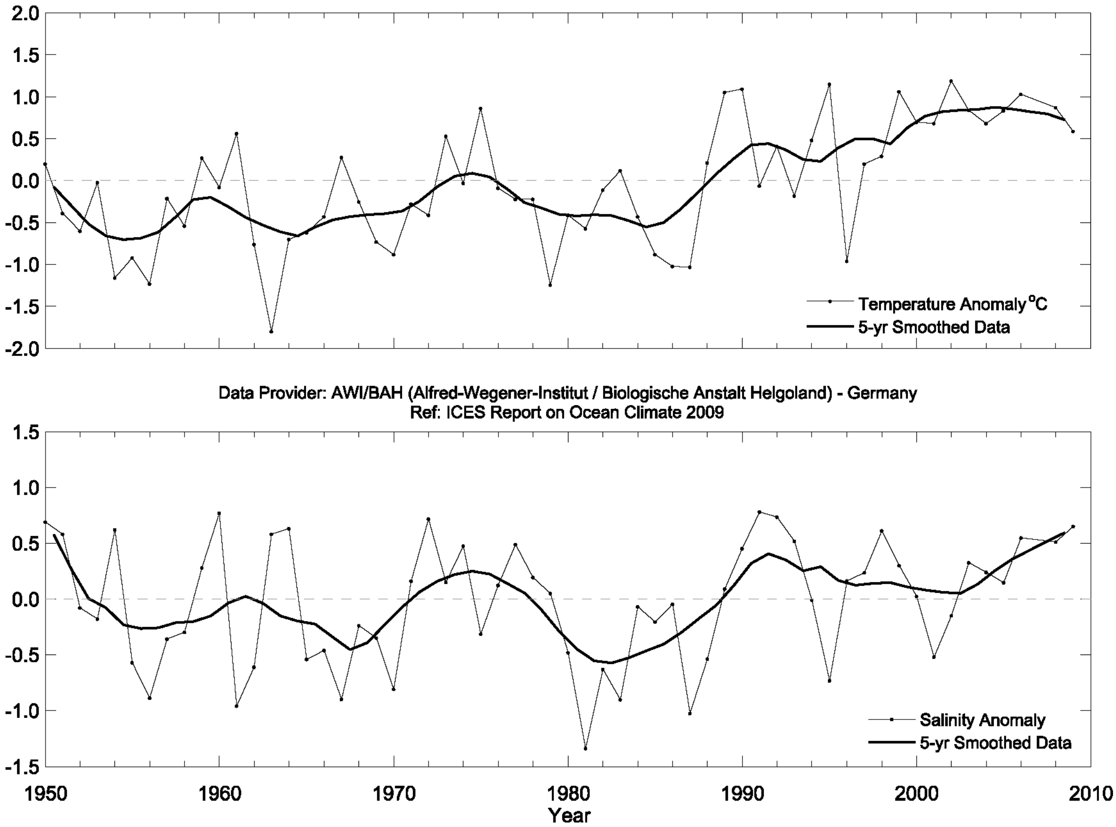


Figure 53.
Area 9 – Southern North Sea. Annual mean surface temperature anomaly (upper panel) and salinity anomaly (lower panel) at Station Helgoland Roads.

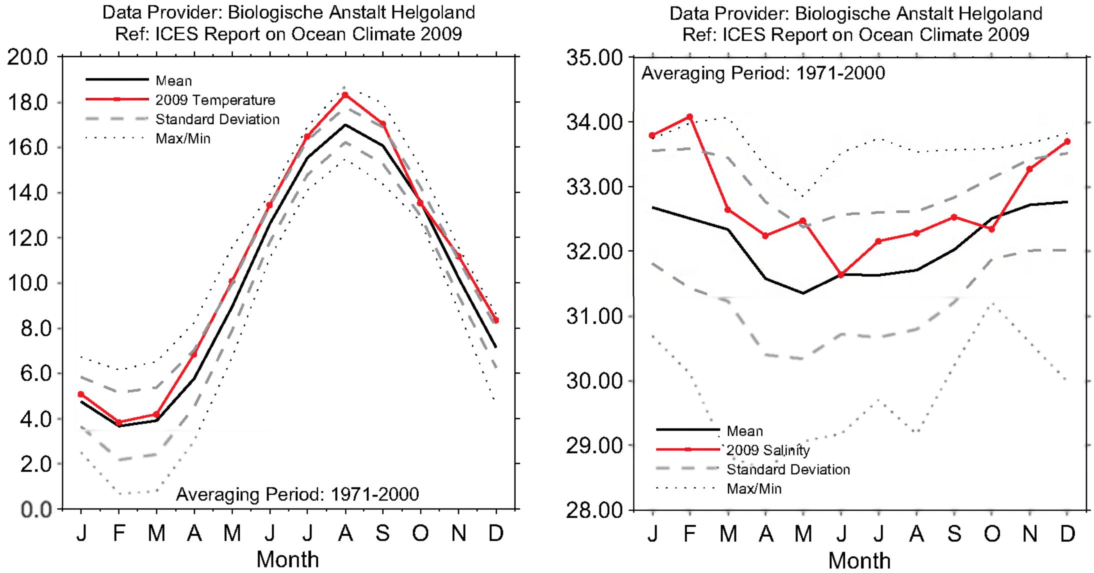


Figure 54.
Area 9 – Southern North Sea. 2009 monthly surface temperature (left panel) and salinity (right panel) at Station Helgoland Roads.

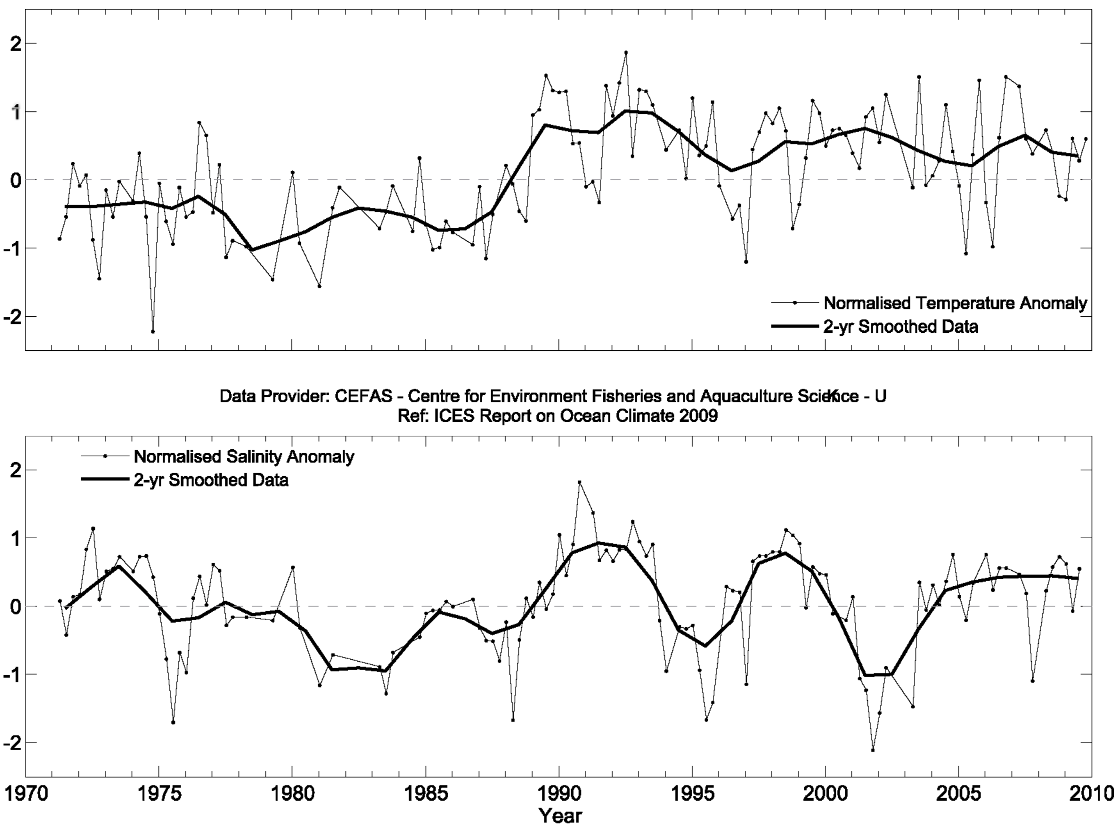


Figure 55.
Area 9 – Southern North Sea. Normalized sea surface temperature anomaly (upper panel) and salinity anomaly (lower panel) relative to 1971–2000, measured along 52°N by a regular ferry at six standard stations. The time-series reveals the seasonal section average (DJF, MAM, JJA, SON) of the normalized variable.

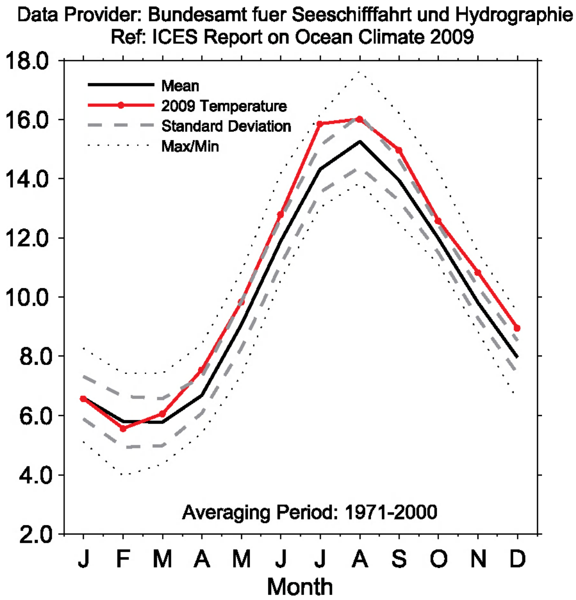


Figure 56.
Areas 8 and 9 – Northern and southern North Sea. North Sea area-averaged sea surface temperature (SST) annual cycle; 2009 monthly means based on operational weekly North Sea SST maps.

4.14 Area 9b – Skagerrak, Kattegat, and the Baltic

THE SEAS IN AREA 9B ARE CHARACTERIZED BY LARGE SALINITY VARIATIONS. IN THE SKAGERRAK, WATER MASSES FROM DIFFERENT PARTS OF THE NORTH SEA ARE PRESENT. THE KATTEGAT IS A TRANSITION AREA BETWEEN THE BALTIC AND THE SKAGERRAK. THE WATER IS STRONGLY STRATIFIED, WITH A PERMANENT HALOCLINE (SHARP CHANGE IN SALINITY AT DEPTH). THE DEEP WATER IN THE BALTIC PROPER, WHICH ENTERS THROUGH THE BELTS AND THE SOUND, CAN BE STAGNANT FOR LONG PERIODS IN THE INNER BASINS. IN THE RELATIVELY SHALLOW AREA IN THE SOUTHERN BALTIC, SMALLER INFLOWS PASS RELATIVELY QUICKLY, AND THE CONDITIONS IN THE DEEP WATER ARE VERY VARIABLE. SURFACE SALINITY IS VERY LOW IN THE BALTIC PROPER AND THE GULF OF BOTHNIA. THE LATTER AREA IS ICE COVERED DURING WINTER.

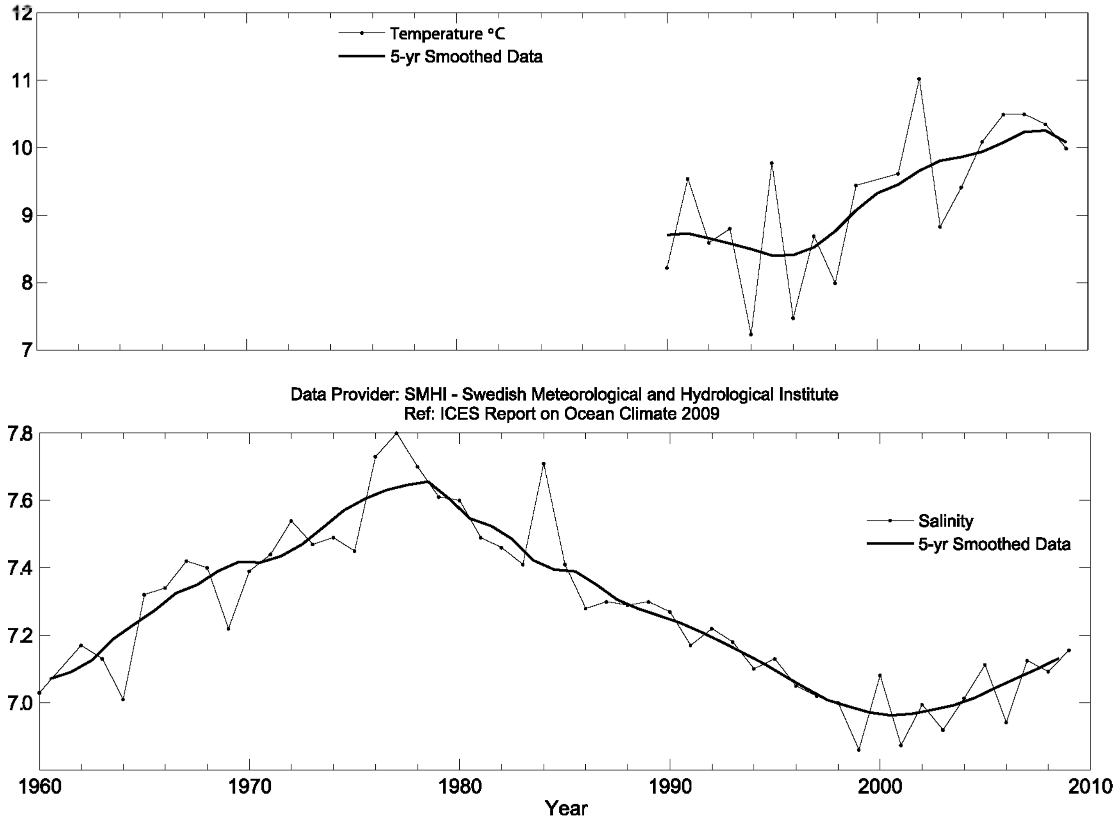
Owing to its central location relative to the Skagerrak, Kattegat, and Baltic, the weather in Sweden can be taken as representative for the area. The mean air temperature during 2009 was 0.5–1.5°C above normal in most parts of Sweden, but below the temperatures of the previous years. In contrast to 2007 and 2008, the beginning of 2009 was cold. April was sunny and warm, whereas the beginning of summer was unusually cold. Highest air temperatures were obtained at the end of June/ beginning of July. At the end of December, the whole country was covered with snow. Precipitation was higher than normal except in the northernmost and southernmost parts of Sweden. Winds were somewhat weaker than normal, as in 2008, and the number of sun-hours was above normal in most places.

Surface water temperature was close to normal in the Baltic Proper for the entire year, whereas salinity was slightly above normal. In Skagerrak and the northern part of Kattegat, the surface water in February was colder and less saline than normal. At the end of June, the sea surface temperature was well above normal in Kattegat and Skagerrak. As a result of strong westerly winds at the beginning of October, the surface salinity became unusually high in this area. In the Bothnian Bay and Bothnian Sea, the surface salinity was close to normal.

A storm over the southern parts of the Baltic in the middle of November gave rise to an inflow to the deeper parts of the Arkona and Bornholm basins, improving oxygen conditions in this area.

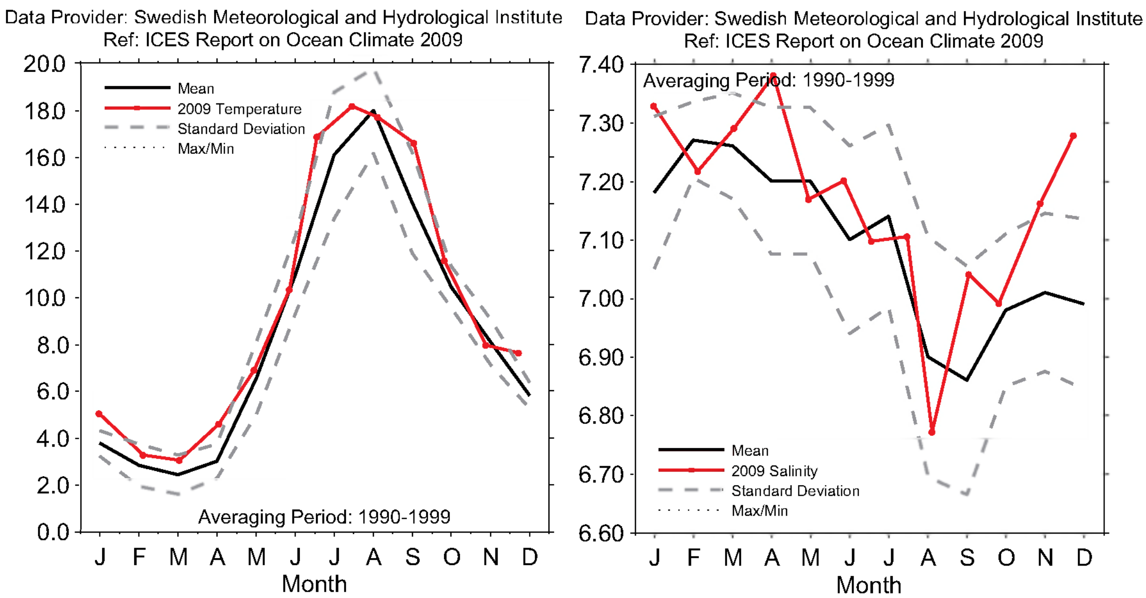
The 2008/2009 ice season was considered mild, but the maximum ice extent was still more than twice that of the previous season. The maximum ice extent occurred on 20 February, which was quite early.

Figure 57.
Area 9b – Skagerrak, Kattegat, and the Baltic. Surface temperature (upper panel) and surface salinity (lower panel) at Station BY15 (east of Gotland) in the Baltic Proper.



STILL WARMER THAN NORMAL IN SKAGERRAK, KATTEGAT, AND THE BALTIC IN 2009.

Figure 58.
Area 9b – Skagerrak, Kattegat, and the Baltic. 2009 monthly surface temperature (left panel) and salinity (right panel) at Station BY15 (east of Gotland) in the Baltic Proper.



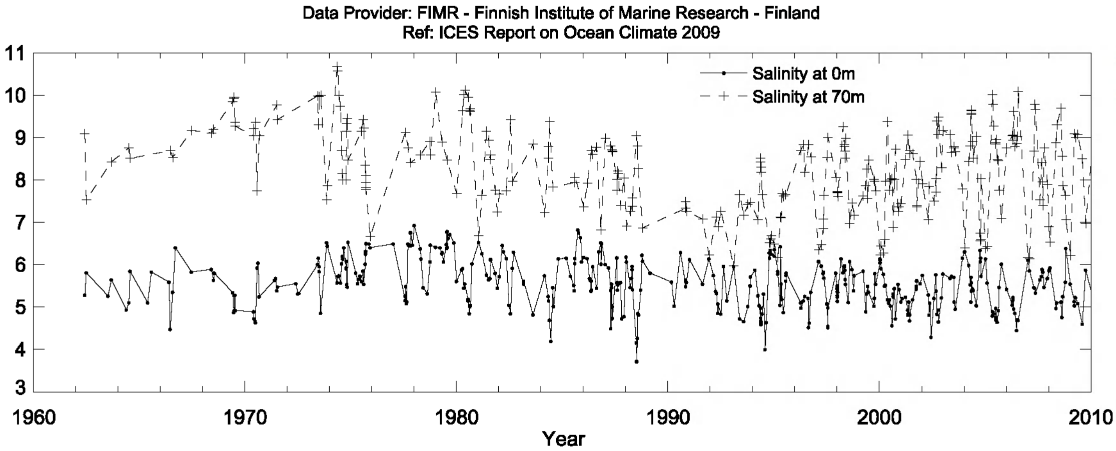


Figure 59.
Area 9b – Skagerrak, Kattegat, and the Baltic. Salinity at Station LL7 in the Gulf of Finland.

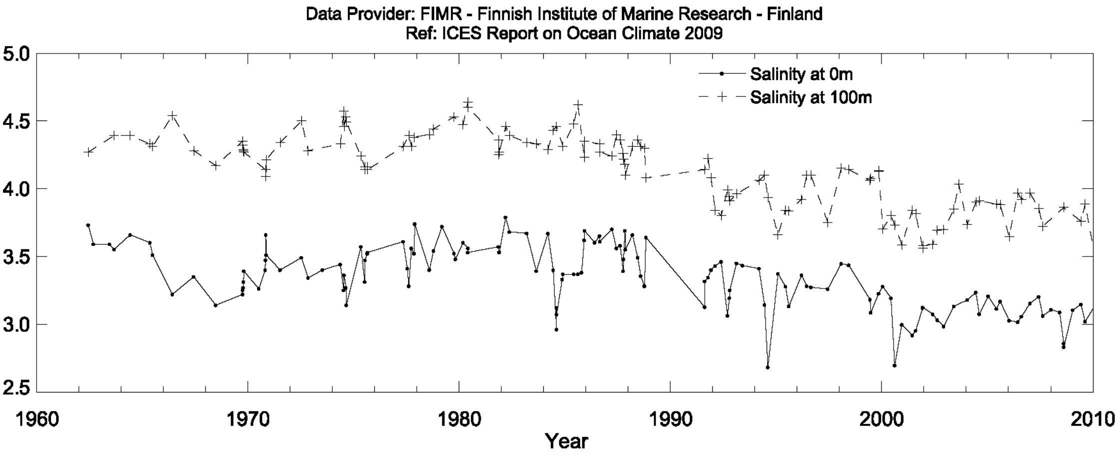


Figure 60.
Area 9b – Skagerrak, Kattegat, and the Baltic. Salinity at Station B03 in Bothnian Bay.

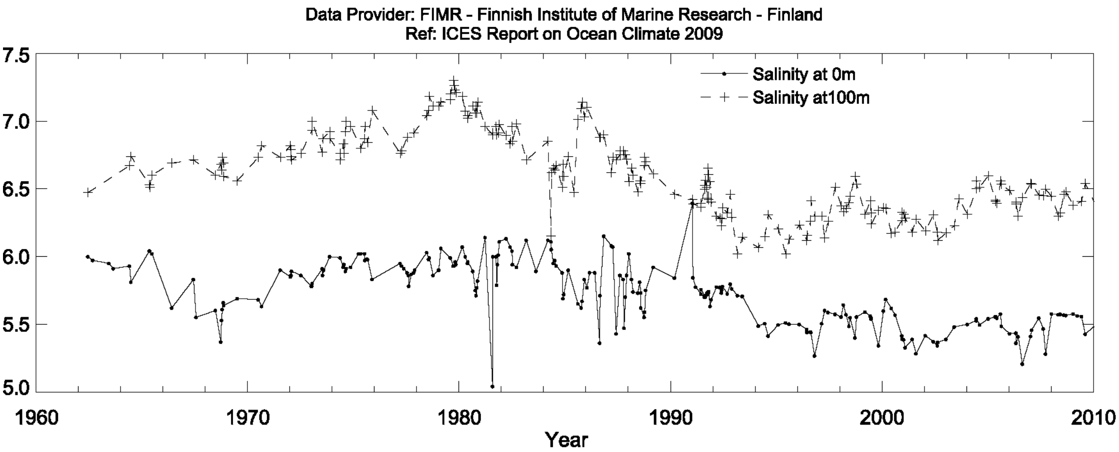


Figure 61.
Area 9b – Skagerrak, Kattegat, and the Baltic. Salinity at Station SR5 in the Bothnian Sea.

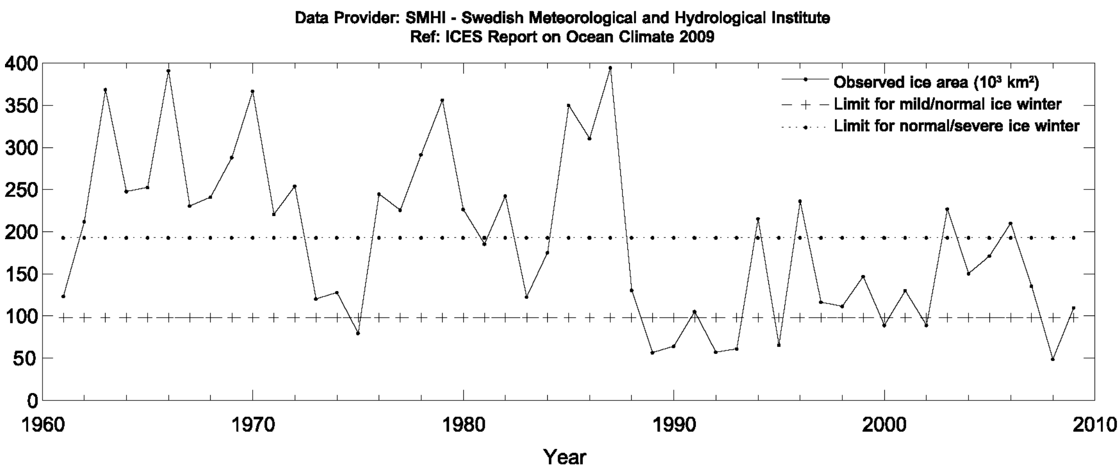


Figure 62.
Area 9b – Skagerrak, Kattegat, and the Baltic. The ice extent in the Baltic since 1961.

4.15 Area 10 – Norwegian Sea

THE NORWEGIAN SEA IS CHARACTERIZED BY WARM ATLANTIC WATER ON THE EASTERN SIDE AND COLD ARCTIC WATER ON THE WESTERN SIDE, SEPARATED BY THE ARCTIC FRONT. ATLANTIC WATER ENTERS THE NORWEGIAN SEA THROUGH THE FAROE–SHETLAND CHANNEL AND BETWEEN THE FAROES AND ICELAND VIA THE FAROE FRONT. A SMALLER BRANCH, THE NORTH ICELANDIC IRMINGER CURRENT, ENTERS THE NORDIC SEAS ON THE WESTERN SIDE OF ICELAND. ATLANTIC WATER FLOWS NORTH AS THE NORWEGIAN ATLANTIC CURRENT, WHICH SPLITS WHEN IT REACHES NORTHERN NORWAY; SOME ENTERS THE BARENTS SEA, WHILE THE REST CONTINUES NORTHWARDS INTO THE ARCTIC OCEAN AS THE WEST SPITSBERGEN CURRENT.

Three sections from south to north in the eastern Norwegian Sea demonstrate the development of temperature and salinity in the core of the Atlantic Water (AW; Svinøy, Gimsøy, and Sørkapp). In general, there has been an increase in temperature and salinity in all three sections from the mid-1990s to the present. In all three sections, temperature and salinity were above the long-term means in 2009. In 2009, the annual temperature averages were ca. 0.7°C above the long-term mean in both the Svinøy and Gimsøy sections, while in the Sørkapp Section, the summer temperature was 0.5°C above the long-term mean. In 2009, salinity values were 0.09, 0.07, and 0.04 above the long-term means for the time-series in the Svinøy, Gimsøy, and Sørkapp sections, respectively. The high salinity values reflect saltier AW in the Faroe–Shetland Channel.

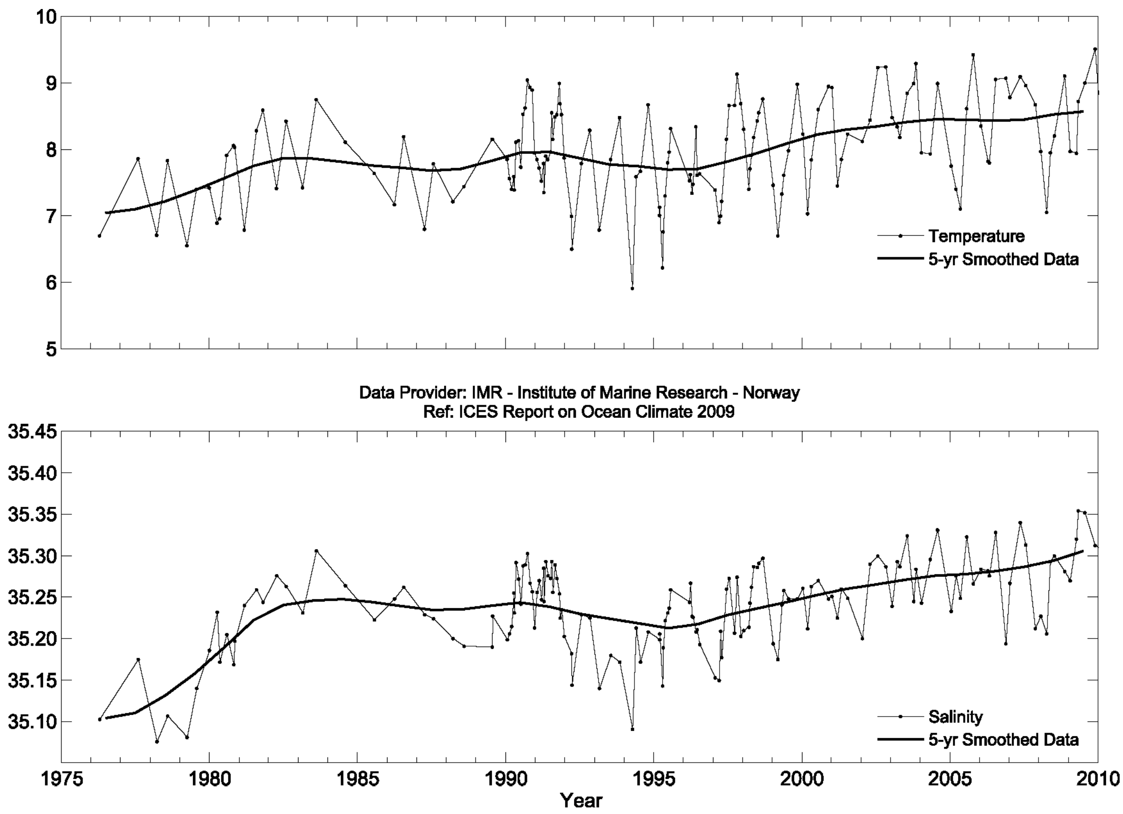


Figure 63.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Svinøy Section (63°N).

ABOVE-AVERAGE TEMPERATURE AND SALINITY IN THE NORWEGIAN SEA IN 2009.

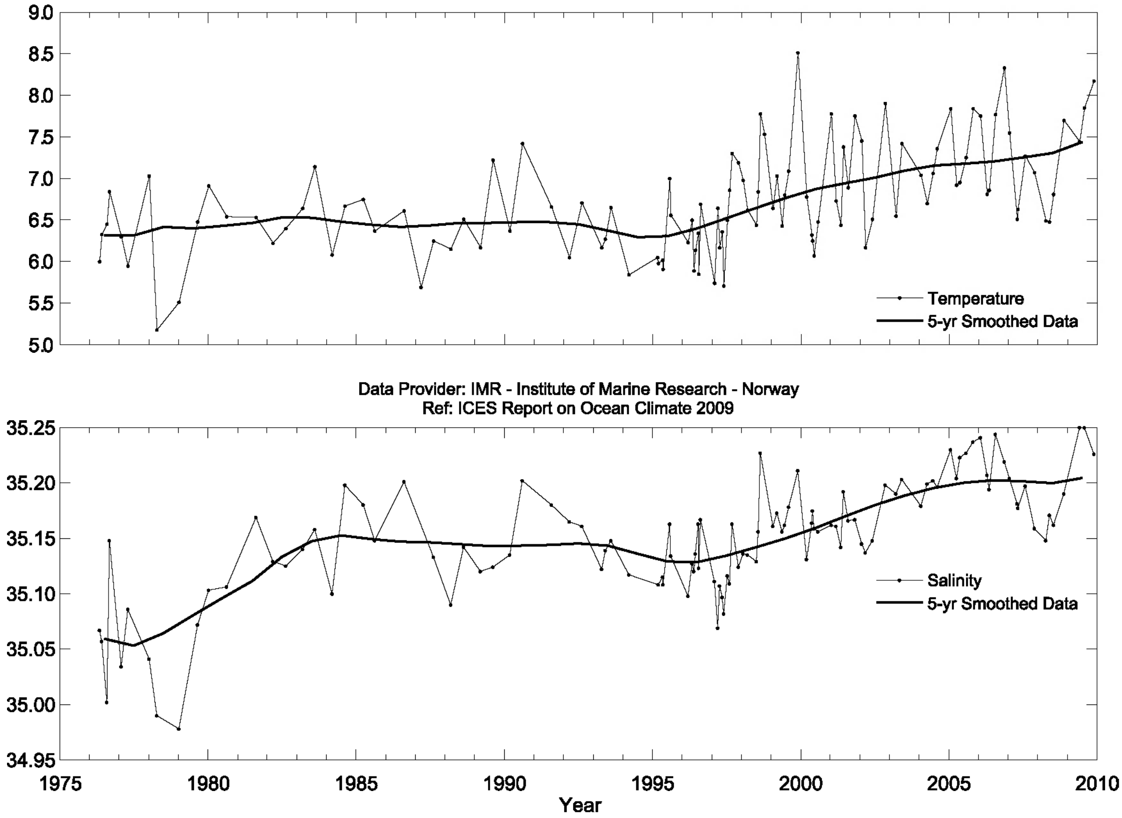


Figure 64.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Gimsøy Section (69°N).

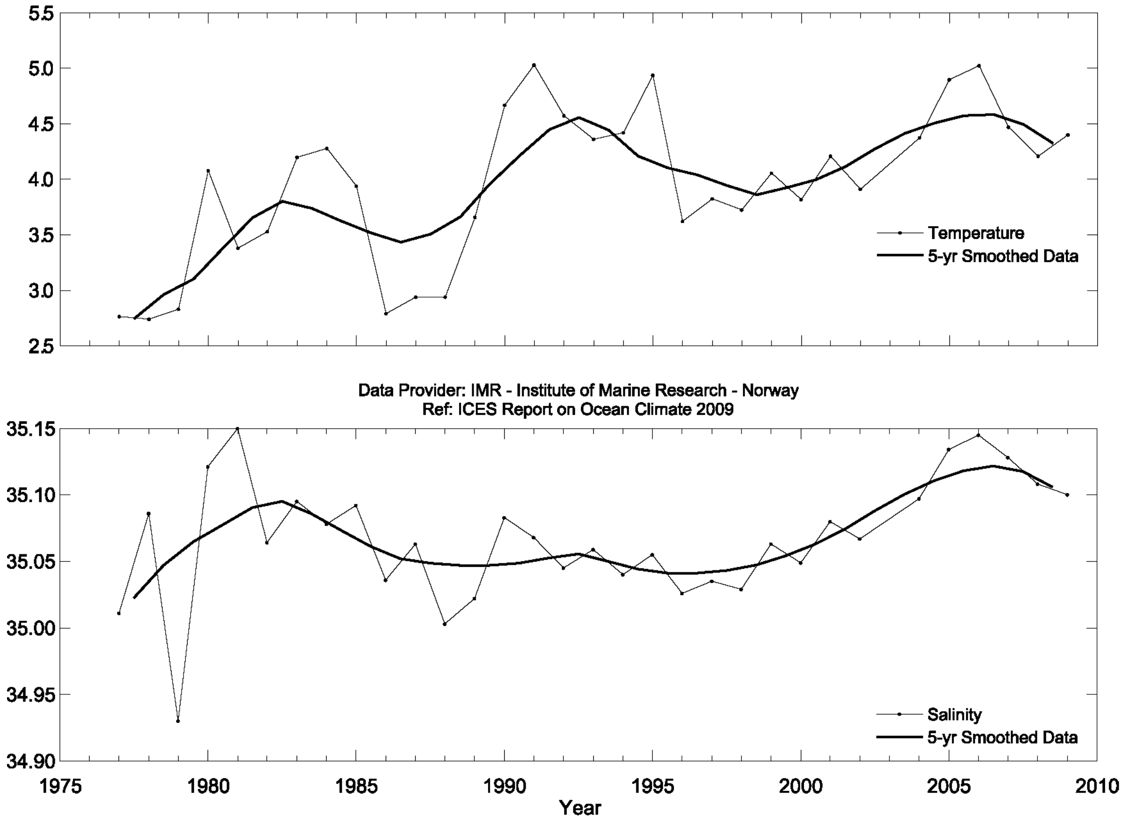


Figure 65.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Sørkapp Section (76°N).

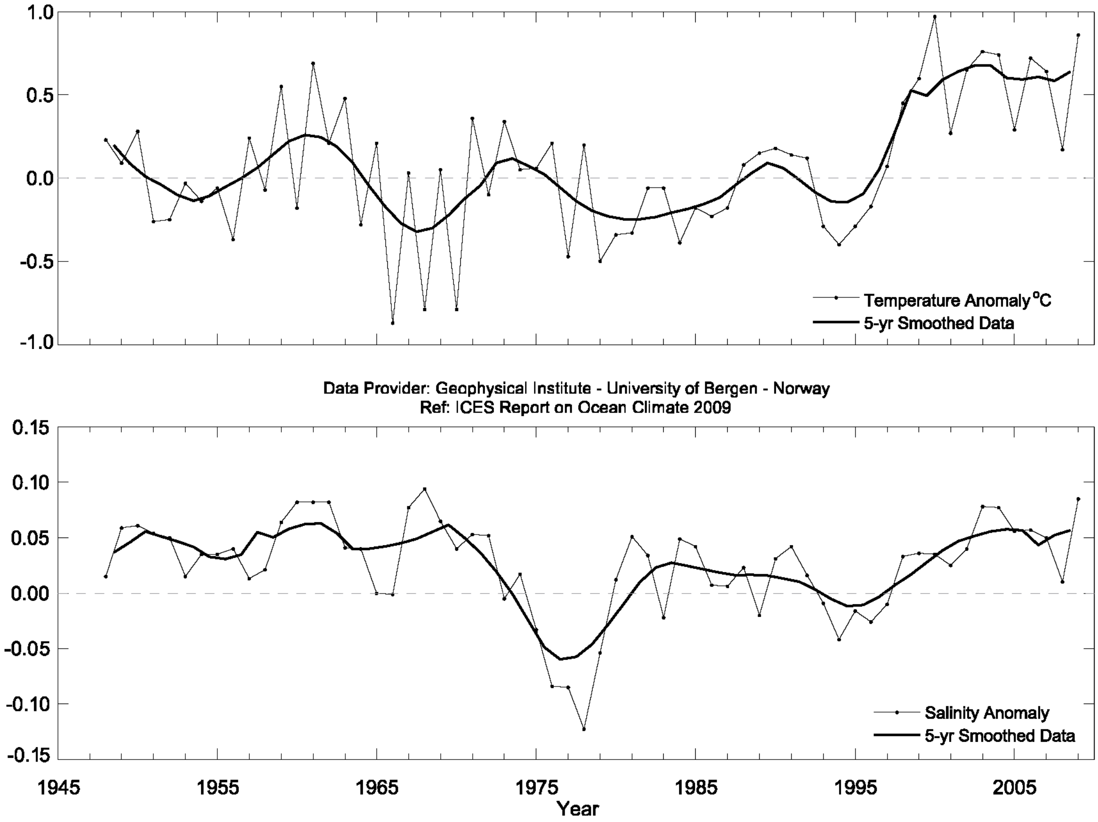


Figure 66.
Area 10 – Norwegian Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) at 50 m at Ocean Weather Station "M" (66°N 2°E).

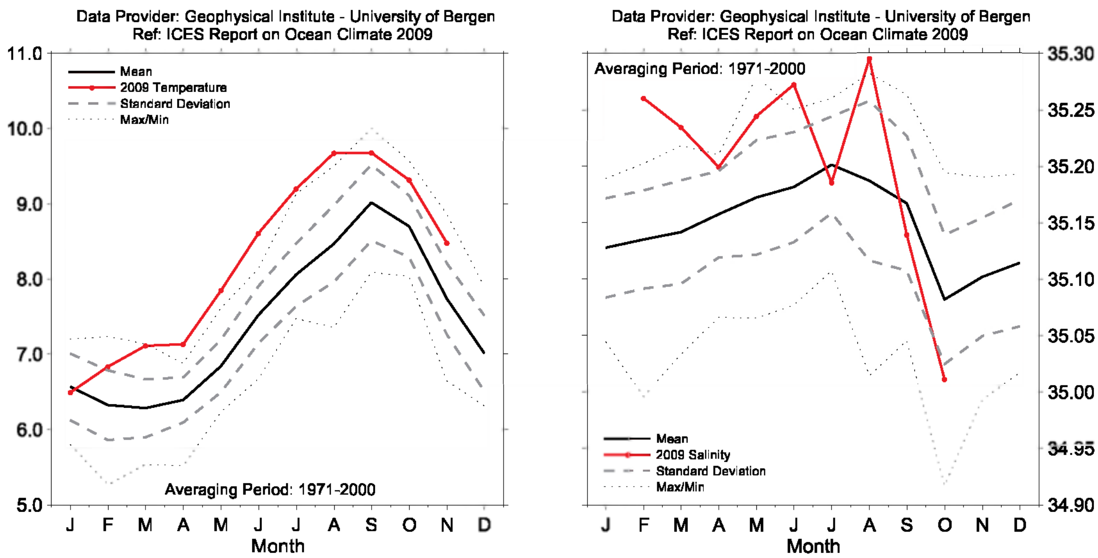


Figure 67.
Norwegian Sea. 2009 monthly temperature (left panel) and salinity (right panel) at 50 m at Ocean Weather Station "M" (66°N 2°E).

4.16 Area 11 – Barents Sea

THE BARENTS SEA IS A SHELF SEA, RECEIVING AN INFLOW OF WARM ATLANTIC WATER FROM THE WEST. THE INFLOW DEMONSTRATES CONSIDERABLE SEASONAL AND INTERANNUAL FLUCTUATIONS IN VOLUME AND WATER MASS PROPERTIES, PARTICULARLY IN HEAT CONTENT AND, CONSEQUENTLY, ICE COVERAGE.

In 1996 and 1997, after a period with high temperatures in the first half of the 1990s, temperatures in the Barents Sea dropped to values slightly below the long-term average. From March 1998, the temperature in the western Barents Sea increased to just above the average, whereas the temperature in the eastern part remained below the average during 1998. From the beginning of 1999, there was a rapid temperature increase in the western Barents Sea that also spread to the eastern part. Since then, the temperature has remained above average.

In the southern Barents Sea, the water temperatures in 2009 were ca. 0.8°C above the long-term means. The temperature of the Atlantic Water was 0.5–1.6°C higher than the average throughout the year, depending on time and place. The positive anomalies gradually decreased, from 0.8–1.6°C in January–April to 0.5–0.7°C in August–October, and then increased again to 0.9–1.3°C in November–December. Compared with 2008, the temperature of the upper 200 m layer in the Kola Section was lower in the first half of 2009 and higher in the second half. In the Murmansk Current, the December temperature was the highest since 1951, and the 2009 annual temperature was typical of anomalous warm years and close to that of 2008. Even though the bottom temperature in August–September 2009 was, on average, 0.3–1.0°C higher than normal for most of the Barents Sea, the volume of cold Arctic waters increased significantly in the northern Barents Sea from 2008, and, for the first time in the last three years, waters with a negative temperature were found in the Eastern Basin during this time. Throughout most of the year, the total ice extent was lower than the long-term average, but higher than in 2008.

The volume flux into the Barents Sea varies with periods of several years, and was significantly lower during 1997–2002 than during 2003–2006. The year 2006 was special, as the volume flux had both a maximum (in winter 2006) and a minimum (in fall 2006). Since then, the inflow has been low, particularly during spring and summer. The inflow in 2009 was similar to 2007 and 2008: moderate during winter followed by a strong decrease in spring. In spring 2009, the flux was almost 1.5 Sv below average. There are no observations for autumn 2009. There is no significant trend in the observed volume flux from 1997 to 2009.

TOTAL ICE EXTENT IN THE BARENTS SEA LOWER THAN THE LONG-TERM AVERAGE IN 2009.

The water temperature in the Barents Sea in 2010 is expected to be higher than the long-term mean, but probably lower than in 2009.

The west coast of Scotland from FRV Alba na Mara. Image courtesy of Marine Scotland, Aberdeen UK.

Figure 68.
Area 11 – Barents Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Fugløya–Bear Island Section.

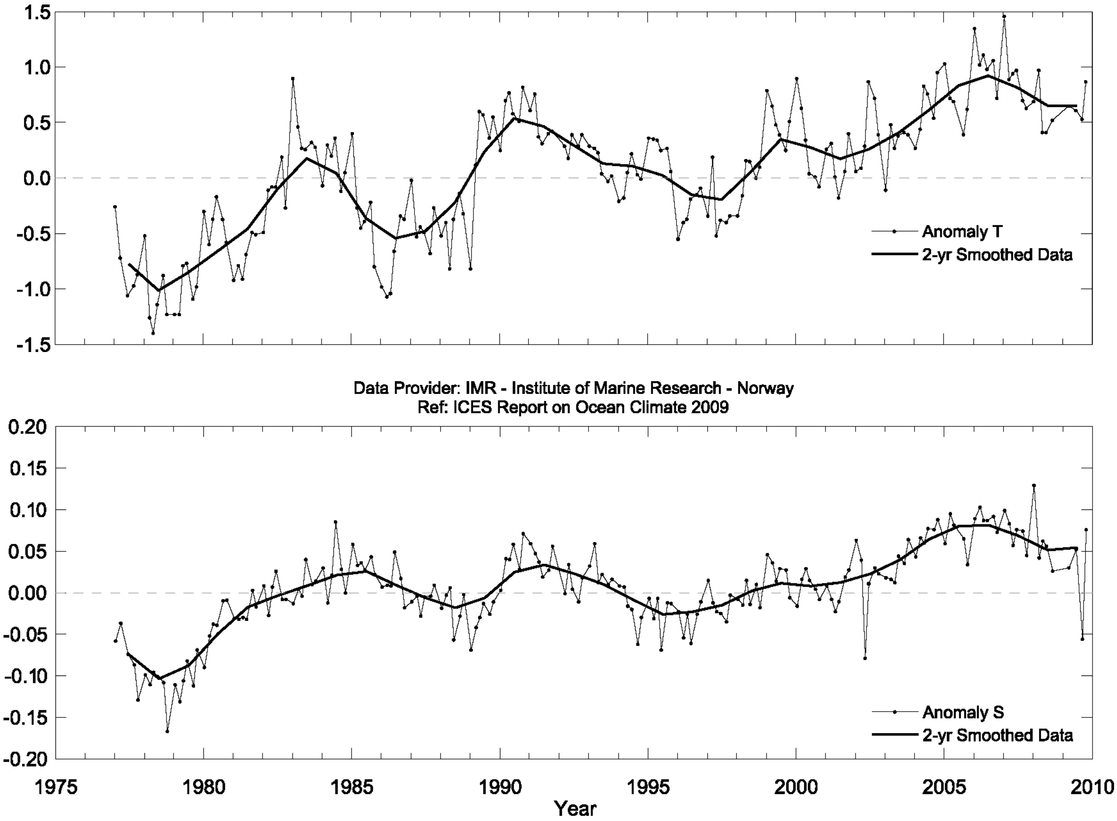
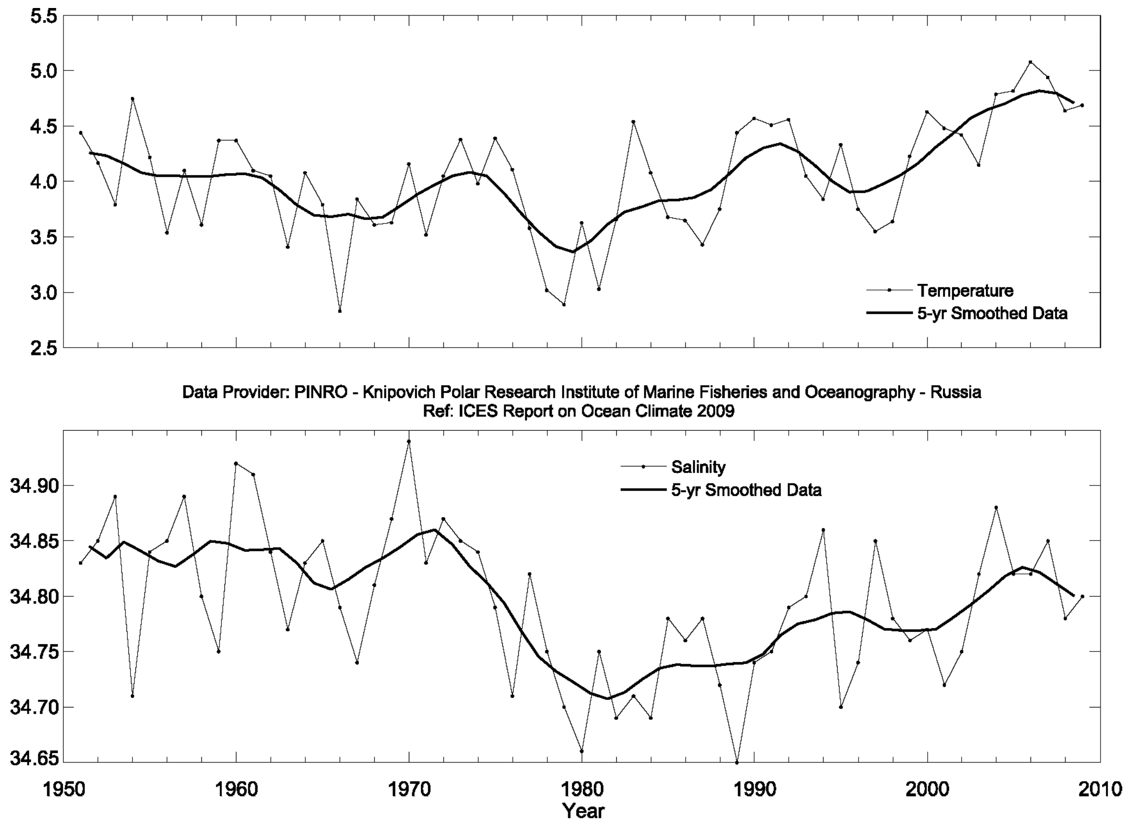


Figure 69.
Area 11 – Barents Sea. Temperature (upper panel) and salinity (lower panel) in the Kola Section (0–200 m).



4.17 Area 12 – Greenland Sea and Fram Strait

FRAM STRAIT IS THE NORTHERN BORDER OF THE NORDIC SEAS. IT IS THE DEEPEST PASSAGE CONNECTING THE ARCTIC TO THE REST OF THE WORLD OCEAN AND ONE OF THE MAIN ROUTES WHEREBY ATLANTIC WATER (AW) ENTERS THE ARCTIC (THE OTHER IS THE BARENTS SEA). THE AW IS CARRIED NORTHWARDS BY THE WEST SPITSBERGEN CURRENT, AND VOLUME AND HEAT FLUXES DEMONSTRATE STRONG SEASONAL AND INTERANNUAL VARIATIONS. A SIGNIFICANT PART OF THE AW ALSO RECIRCULATES WITHIN FRAM STRAIT AND RETURNS SOUTHWARDS (RETURN ATLANTIC WATER). POLAR WATER FROM THE ARCTIC OCEAN FLOWS SOUTH IN THE EAST GREENLAND CURRENT AND AFFECTS WATER MASSES IN THE NORDIC SEAS.

In 2009, the temperature of the Return Atlantic Water (RAW) at the western rim of the Greenland Sea (75°N) was similar to that observed in 2008, whereas salinity decreased slightly. Both values were close to their long-term means. The Atlantic Water (AW) at the eastern rim of the Greenland Sea was not measured in 2009. Temperature and salinity in the upper layer of the central Greenland Basin (within the Greenland Gyre) were modified by the advection of AW and by winter convection. The thermocline and halocline have steadily descended by more than 1000 m since 1993. After winter 2007/2008, a two-layer structure resulted from convection, which supplied both salt and heat to the intermediate layers. In winter 2008/2009, almost half of the Greenland Sea had been shielded from convection as a result of the unusual western location of the Arctic Front. In summer 2009, the western half of the Greenland Gyre was filled with a thick layer of Atlantic-origin water, whereas between 3°W and the Arctic Front, winter convection formed deep, fresher and colder waters. In recent years, the Greenland Sea has been increasingly dominated by the influence of AW inflow. This trend continued in the western half of the Greenland Gyre during 2009, but was interrupted by the freshwater event in the eastern half. However, the volume of classic Greenland Sea Water (salinities below 34.9) was still negligible in 2009.

In 2009, the summer temperature of AW in the southern Fram Strait recovered from the significant decrease observed in 2007 and 2008. At the standard section at 76°30′N, the mean temperature at 200 dbar (averaged between 9° and 12°E) was 3.53°C, which was 0.36° higher than the 1996–2009 mean. The mean salinity at 200 dbar was 35.09, which was 0.031 higher than the 1996–2009 mean.

The long-term temperature and salinity trends over 10 years are positive: 1.06°C and 0.086, respectively.

In the northern Fram Strait, three characteristic areas can be distinguished in relation to the main flows: the West Spitsbergen Current (WSC) between the shelf edge and 5°E, the Return Atlantic Current (RAC) between 3°W and 5°E, and the Polar Water in the East Greenland Current (EGC) between 3°W and the Greenland Shelf. In summer 2009, temperature and salinity were observed to increase in the eastern and central Fram Strait at the standard section (78°50′N) compared with summer 2008. After their record-high maxima in 2006, mean temperature and salinity in the WSC decreased until 2008, when they reached their lowest decadal values. In 2009, both temperature and salinity recovered from the minima, returning to (temperature) or exceeding (salinity) their long-term means. Potential density of the AW in the WSC decreased to the long-term mean value in 2009 after reaching a decadal maximum in 2008.

TEMPERATURE AND SALINITY OF THE ATLANTIC WATER IN THE GREENLAND SEA AND FRAM STRAIT RETURNED TO AVERAGE IN 2009.

As a result of the big pool of the recirculated AW in the central part of Fram Strait, the biggest differences between 2009 and 2008 were found in the RAC. Atlantic Water warmer than 3°C was found across the whole section, whereas in 2008, it was confined only to the WSC. The position of the Arctic Front between Atlantic and Polar Waters at 78°50′N was shifted westwards, from 2°E in 2008 to ca. 2°W in 2009. The salinity in the upper 500 m of the water column was >34.96, except for the Polar Water in the EGC and small surface patches in the central part. As a result, the mean salinity observed in RAC in 2009 was a record high and mean temperature was the second record high, exceeding the long-term mean values by 0.06 (salinity) and 0.64 (temperature).

The winter-centred annual mean of the volume net transport in 2008–2009 was 6.3 Sv, slightly higher than the long-term mean (2002–2009) of 6 Sv. Winter maximum in volume transport was moderate: weaker than in the maximum-transport years (2004/2005 and 2007), but stronger than in the low-transport winters (2003/2004 and 2005/2006). Exceptionally low (for winter) transport was observed in January 2009, followed by strong inflow in late winter and early spring.

Figure 70.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) at 200 m in the Spitsbergen Section (76.50°N).

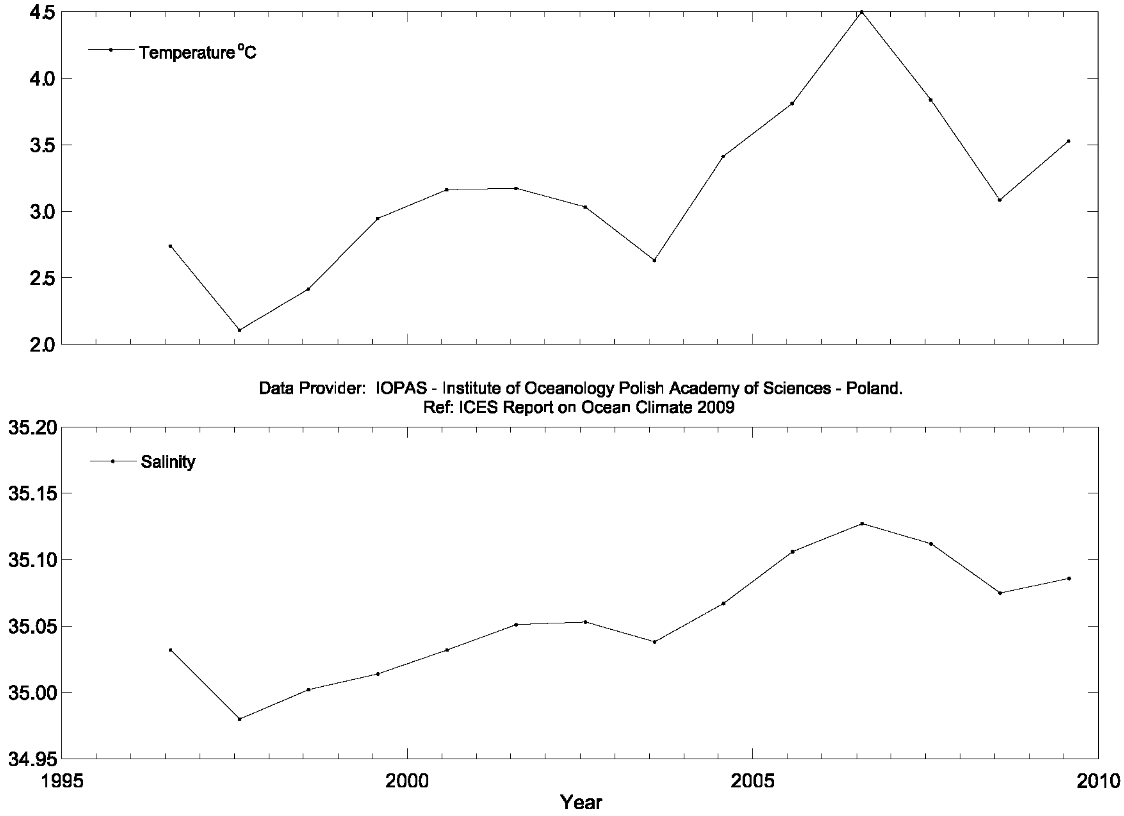
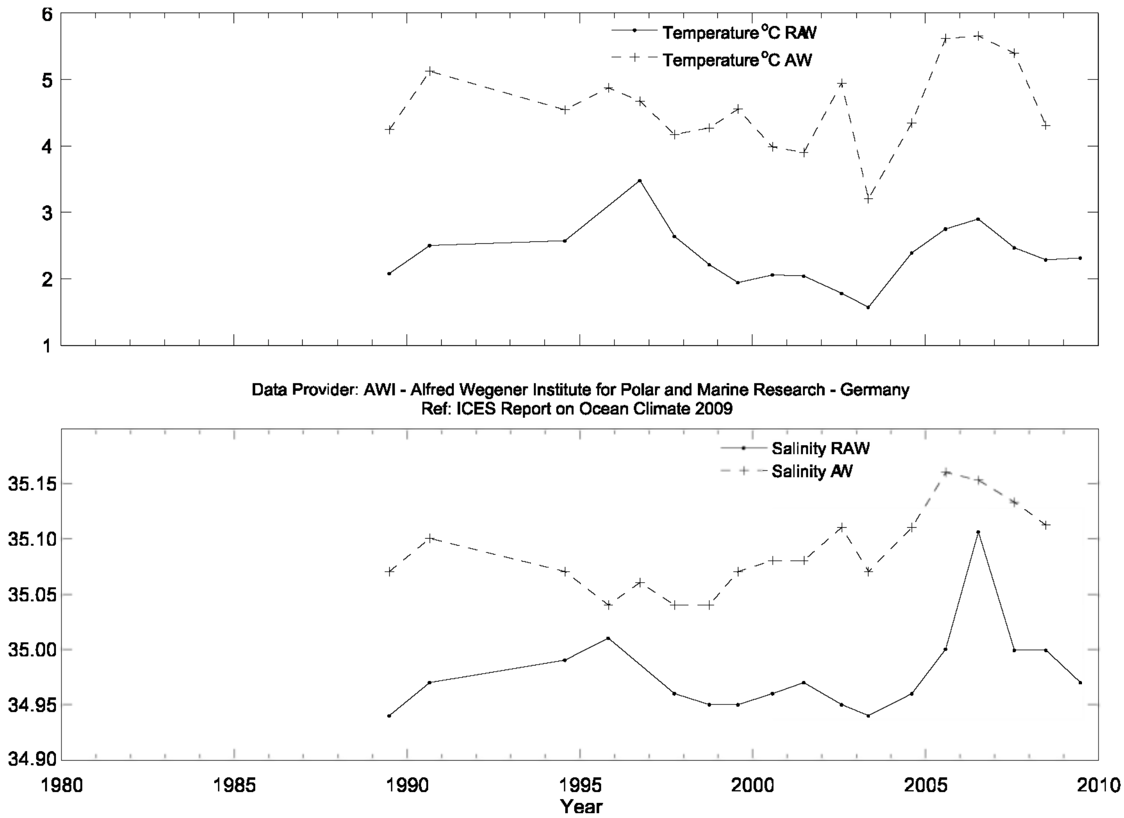


Figure 71.
Area 12 – Greenland Sea and Fram Strait. Temperature anomaly (upper panel) and salinity (lower panel) anomaly of Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea Section at 75°N. AW properties are 50–150 m averages at 10–13°E (not updated for 2009). The RAW is characterized by temperature and salinity maxima below 50 m averaged over three stations west of 11.5°W



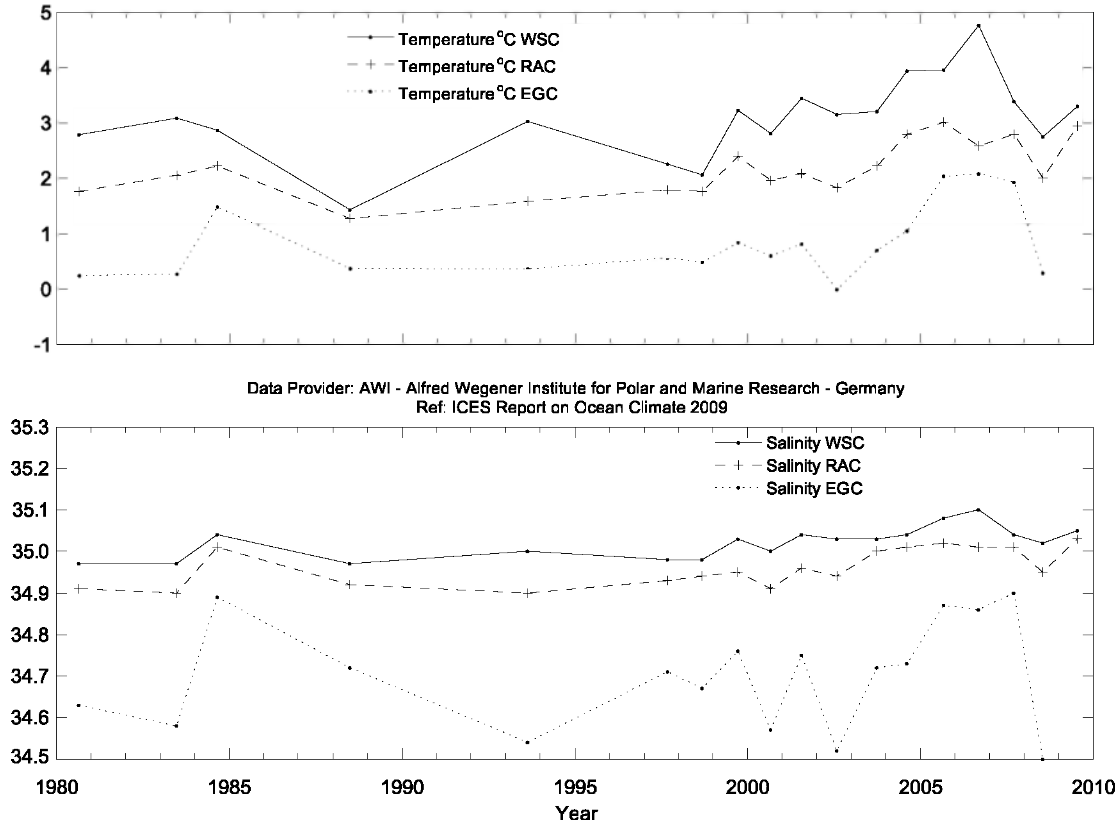


Figure 72.
Area 12 – Greenland Sea and Fram Strait. Temperature anomaly (upper panel) and salinity (lower panel) anomaly in Fram Strait (78.83°N) at 50–500 m: in the West Spitsbergen Current (WSC; between the shelf edge and 5°E), in the Return Atlantic Current (RAC; between 3°W and 5°E), and in the Polar Water in the East Greenland Current (EGC; between 3°W and the Greenland Shelf; not updated for 2009).

RDI ADCP ready for deployment. Image courtesy of Marine Scotland, Aberdeen, UK.

5. DETAILED AREA DESCRIPTIONS, PART II: THE DEEP OCEAN

5.1 Introduction

In this section, we focus on the deeper waters of the Nordic seas and the North Atlantic, typically below 1000 m. The general circulation scheme and dominant water masses are given in Figure 73.

AT THE NORTHERN BOUNDARY OF OUR REGION OF INTEREST, THE COLD AND DENSE OUTFLOW FROM THE ARCTIC OCEAN ENTERS FRAM STRAIT AND REACHES THE GREENLAND SEA. THE OUTFLOW IS A MIXTURE OF EURASIAN BASIN AND CANADIAN BASIN DEEP WATERS AND UPPER POLAR DEEP WATER (UPDW). THE EURASIAN DEEP WATER FEEDS THE DENSEST WATER OF ALL NORDIC SEAS: THE GREENLAND SEABED WATER. THE CANADIAN BASIN DEEP WATER AND UPDW SUPPLY THE ARCTIC INTERMEDIATE WATER IN THE GREENLAND SEA, AND THE UPDW ALSO INCLUDES PRODUCTS OF THE WINTER CONVECTION.

THE DEEP SOUTHWARD OUTFLOW FROM THE NORTH ATLANTIC IN THE DEEP WESTERN BOUNDARY CURRENT IS FED BY THE COLD AND DENSE OVERFLOW WATERS. THE DEEPEST AND DENSEST IS THE DENMARK STRAIT OVERFLOW WATER. THIS WATER MASS ORIGINATES IN THE ARCTIC INTERMEDIATE WATER PRODUCED IN THE GREENLAND AND ICELAND SEAS BY WINTER CONVECTION AND MIXING WITH SURROUNDING WATER MASSES. THE DENMARK STRAIT OVERFLOW WATER SINKS TO THE BOTTOM AS IT PASSES OVER THE DENMARK STRAIT SILL, VIGOROUSLY ENTRAINING AMBIENT WATER. DOWNSTREAM, IT IS OVERLAIN BY AN INTERMEDIATE WATER MASS, THE LABRADOR SEAWATER, FORMED BY DEEP WINTER CONVECTION IN THE LABRADOR SEA. THE MIDDLE LAYER OF THE DEEP, COLD-WATER EXPORT IN THE DEEP WESTERN BOUNDARY CURRENT IS SUPPLIED BY THE ICELAND–SCOTLAND OVERFLOW WATER, ORIGINATING IN WATER MASSES FORMED IN THE NORWEGIAN SEA (ARCTIC INTERMEDIATE WATER AND NORTH ATLANTIC DEEP WATER). PASSING THROUGH THE ICELANDIC BASIN, THE ICELAND–SCOTLAND OVERFLOW WATER ALSO ENTRAINS UPPER OCEAN WATER AND LABRADOR SEAWATER. THE DEEP ANTARCTIC BOTTOM WATER ENTERS THE NORTH ATLANTIC ON THE WESTERN SIDE AND SOME OF THE LOWER DEEP WATER ACCOMPANIES THE INFLOW OF MEDITERRANEAN WATER ON THE EASTERN SIDE.

Figure 73.
Schematic circulation of the intermediate to deep waters in the Nordic seas and North Atlantic.

5.2 Nordic seas deep waters

The longest time-series (from Ocean Weather Station 'M' in the Norwegian Sea, Area 10) reveals warming since the mid-1980s. After a slight decrease in 2003, temperature at 2000 m has steadily increased, reaching –0.80°C in 2008 and 2009. Continuous warming has been observed in the Greenland Sea deep layer at 3000 m (Area 12). In the Iceland Sea, an increase in temperature in the depth range 1500–1800 m has been found since the beginning of the time-series (early 1990s), reaching the annual mean value of –0.78°C (and a record-high value of –0.774°C in summer) in 2009. The long-term warming rates per decade are 0.131°C (Greenland Sea), 0.06°C (Norwegian Sea), and 0.063°C (Iceland Sea). The source of the warming is the deep outflow from the Arctic Ocean, a south-flowing current of the Eurasian and Canadian Basin Deep Waters and the upper Polar Deep Water found on the western side of Fram Strait at ca. 2000 m depth. The Greenland Sea Deep Water (GSDW) is warming fastest owing to its direct contact with this Arctic outflow, whereas the Iceland and Norwegian seas are warming more slowly because they are products of the mixing of their own ambient waters with GSDW and Arctic outflow water.

Warming in the Greenland Sea was accompanied by a year-to-year increase in salinity. Although the temperatures in the bottom-most waters increased from –0.982°C in 2008 to –0.969°C in 2009, there was no temperature change above 2500 m in the lower layer of the Greenland Sea (below the upper boundary defined by the salinity gradient at ca. 1800 m). The temperature structure in the deep ocean at the Greenland continental slope in 2009 was particularly indicative of a deep-water export there. Salinities in the bottom-most waters were 34.9150 in 2008 and 34.9152 in 2009. Salinities in the deep waters of the Greenland Gyre have obviously attained the values of the deep Arctic outflow and, therefore, cannot rise farther (unless the outflow properties change), but the continuing deep-water temperature increase demonstrates that deep Arctic waters were also persistently mixed into the GSDW in 2009. The observed increase in the GSDW salinity may be the result of an adjustment to the Arctic outflow in the continued absence of deep convection and an increased presence of Atlantic Water (AW) in the upper layer. It is unclear whether there has been any corresponding salinity trend in either the Norwegian or the Iceland Sea Deep Waters in recent decades. After some decrease in the early 1990s, salinity in both deep basins has remained relatively stable for the past decade, with a slight increase in the Norwegian Sea since 2005.

The doming structure in the Greenland Gyre is being replaced by a two-layered water mass arrangement, after a cessation of deep convection. Since the beginning of measurements in 1993, the winter convection depth has varied between 700 and 1600 m and has only been significantly deeper in small-scale convective eddies. The import of warm and salty AW to the Greenland Sea is currently not balanced by an import of cool and fresh Polar Waters from the north. The AW, which dominated changes in the upper ocean, took over the role of former ice production as a source of salt and densification in the context of winter convection. The input of AW tends to prevent ice formation and to vertically homogenize the waters ventilated by convective processes.

THE DEEP WATERS OF THE GREENLAND, ICELAND, AND NORWEGIAN SEAS ARE ALL WARMING.

Since 2008, the assessment of the convection history in the central Greenland Sea was more ambiguous than before. The reason was the twofold structure, stemming from convection in winter 2007/2008. After this winter, temperatures and salinities were vertically quite homogenous down to 1600 m, and stabilities attained a long-term minimum as a result of a mixed-layer type convection. However, almost half of the Greenland Sea had been shielded from convection because of the unusual western location of the Arctic Front (boundary between the AWs and Greenland Sea Waters). The laterally bi-parted structure remained until winter 2008/2009, modified by advection. In summer 2009, the western half of the Greenland Gyre was filled with a thick layer of AW derivates, whereas between ca. 3°W and the Arctic Front, winter convection introduced fresher and colder waters downwards in the classical manner of Greenland Sea convection. Despite this freshening event, the volume of GSWD (classified in the 1990s as salinities below 34.9) was negligible in 2009. Data from the moored profiler in the central Greenland Sea in 2008–2009 demonstrate that winter convection distributed the fresher surface waters from summer and autumn 2008 downwards to ca. 1200 m. In summer 2009, the low-stability pool was found directly above 1600 m, slightly enlarged from 2008. From this, a maximum convection depth of ca. 1600 m can be derived for winter 2008/2009.

Figure 74.
Area 12 – Greenland Sea and Fram Strait. Winter convection depths in the Greenland Sea Section at 75°N.

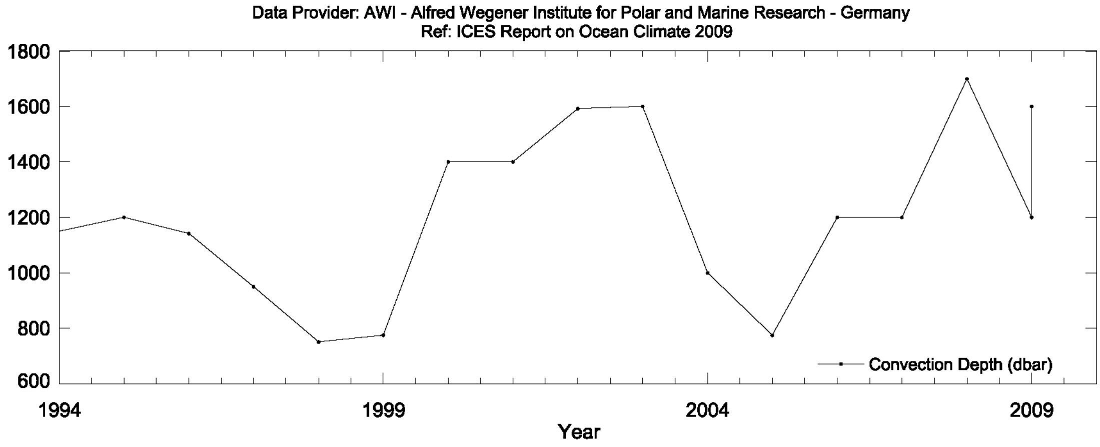
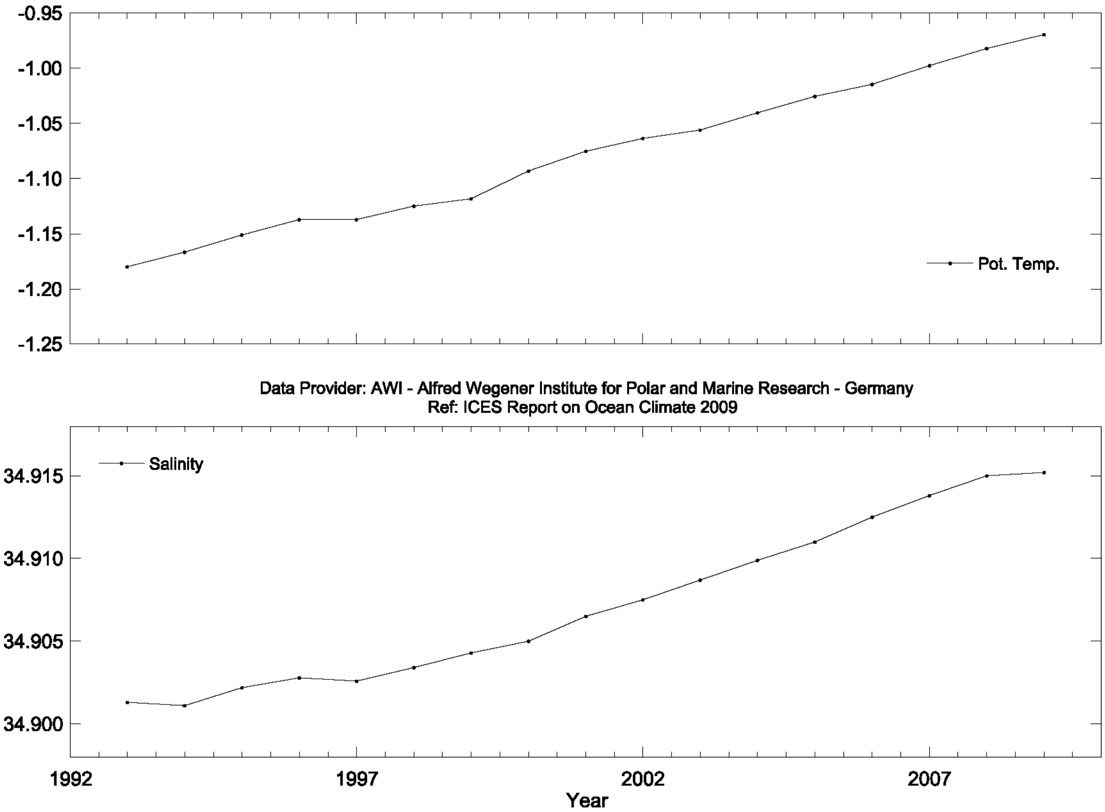


Figure 75.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) at 3000 m in the Greenland Sea Section at 75°N.



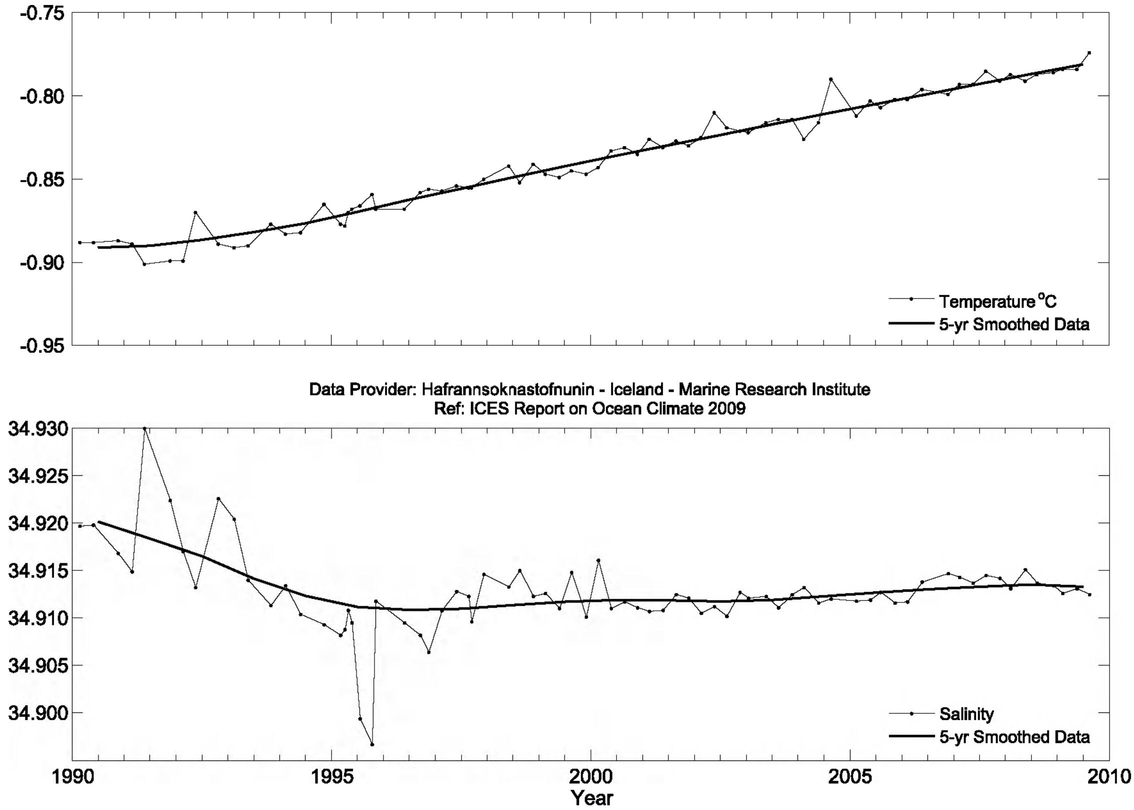


Figure 76.
Area 3 – Icelandic waters. Temperature at 1500–1800 m in the Iceland Sea (68°N 12.67°W).

5.3 North Atlantic deep waters

In the deep layers of the Faroe–Shetland Channel (Area 7), the properties at 800 m are the same as those of Norwegian Sea Deep Water as it passes through the Channel back into the North Atlantic. After a period of decline in the 1990s, temperature has increased since 2000, but still remains lower than the highest temperatures observed in the 1950s, 1960s, and early 1980s. The relatively stable salinity in the first period of measurements (1950 to mid-1970s) was followed by a slow decline through the subsequent 15 years; since 1992, it has stabilized again.

The salinity and potential temperature of the Denmark Strait Overflow Water (DSOW) near Cape Farewell (Area 5b) demonstrated correlated interannual variations between 1991 and 2007 (correlation = 0.7). However, after 2007, the changes in temperature and salinity altered, and the correlation was reduced to ca. 0.5, which implies that less than 30% of the variance of the salinity can be explained by the variance of the temperature. The density of the DSOW hardly changes on long time-scales. Measurements with moored instrumentation have demonstrated that temperature and density mainly vary at an annual time-scale, possibly forced by wind-driven processes near Denmark Strait.

The properties of the North Atlantic Deep Water (NADW) in the deep boundary current west of Greenland (Area 1) are monitored at 2000 m depth at Cape Desolation Station 3. The temperature and salinity of this water underwent strong interannual variability during the 1980s. Since the beginning of 1990s, both characteristics were decreasing and reached their minimal values in 1998. After that, positive trends were observed until 2007. In 2007, the temperature of the NADW started to decrease but its salinity was unchanged. In 2009, the temperature of the water was lower than in 2008 and 2007 and only 0.02°C above the long-term mean, referenced to 1983–2000. The salinity in 2009 was slightly lower than in 2008 and 2007, but was still 0.01 above normal.

Figure 77.
Area 10 – Norwegian Sea. Temperature (upper panel) and salinity (lower panel) at 2000 m at Ocean Weather Station "M" (66°N 2°E).

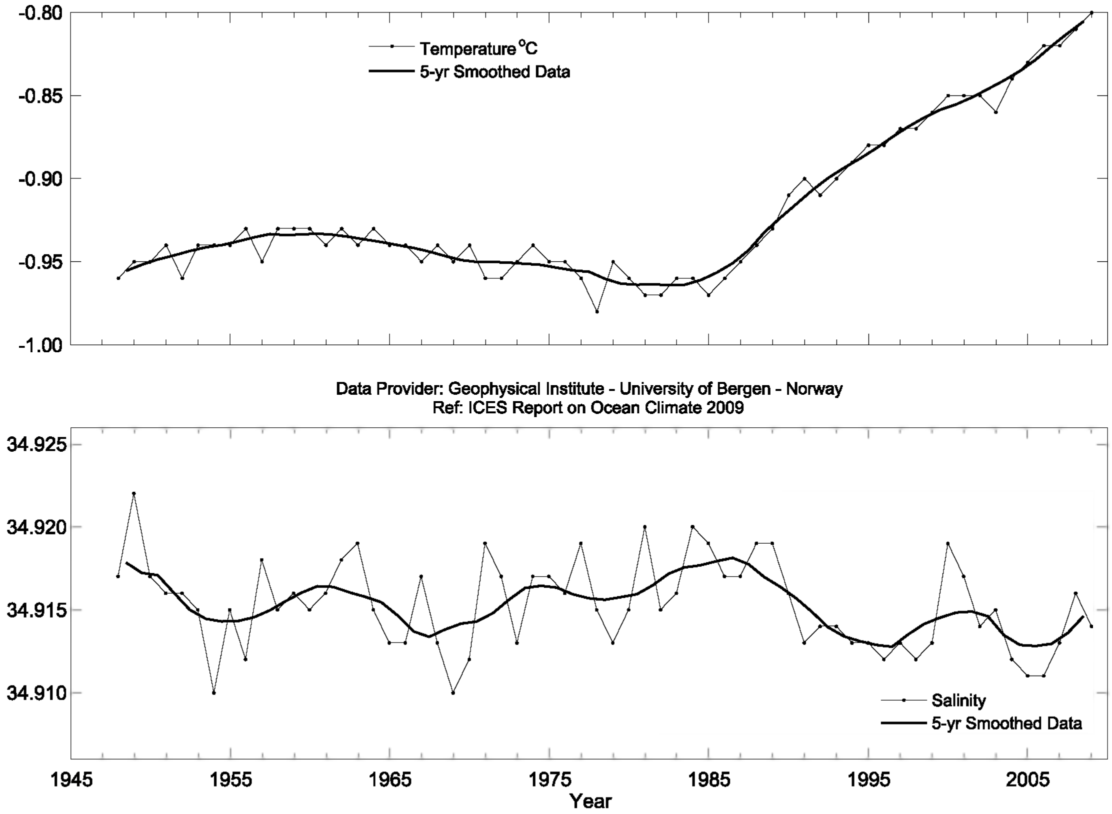
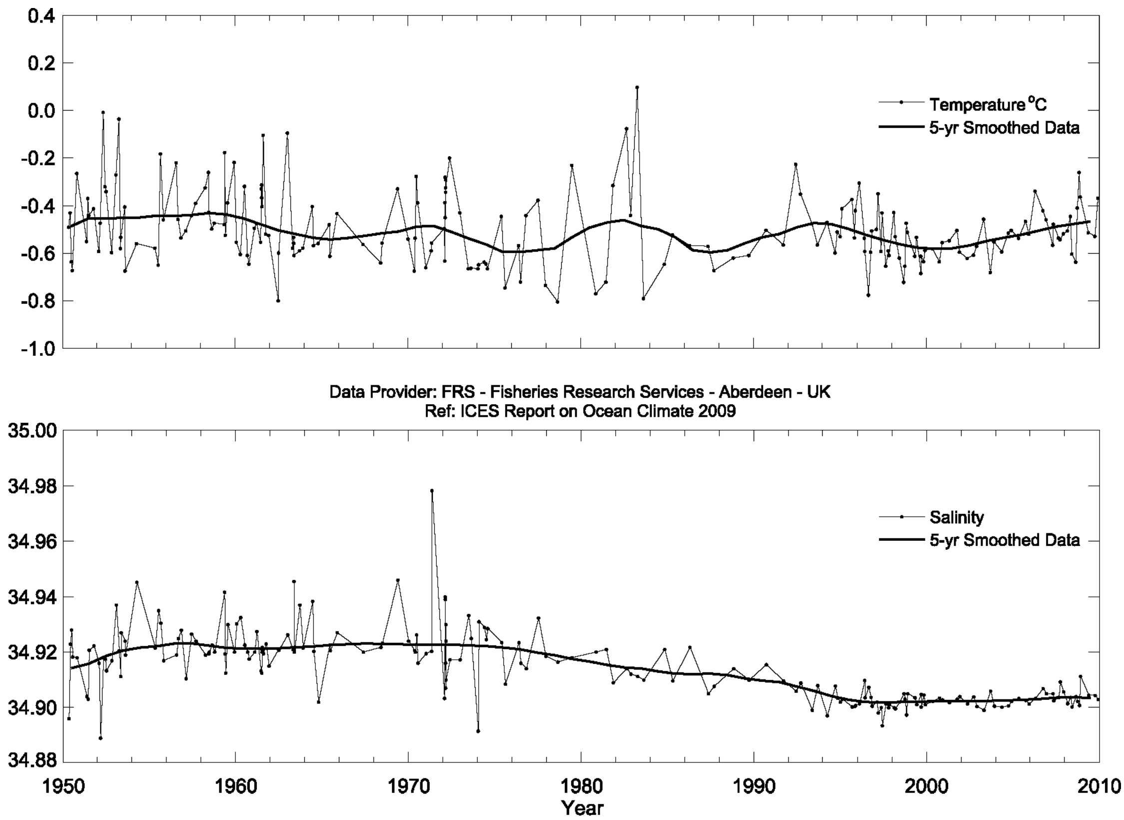


Figure 78.
Area 7 – Faroe–Shetland Channel. Temperature (upper panel) and salinity (lower panel) at 800 m in the Faroe–Shetland Channel.



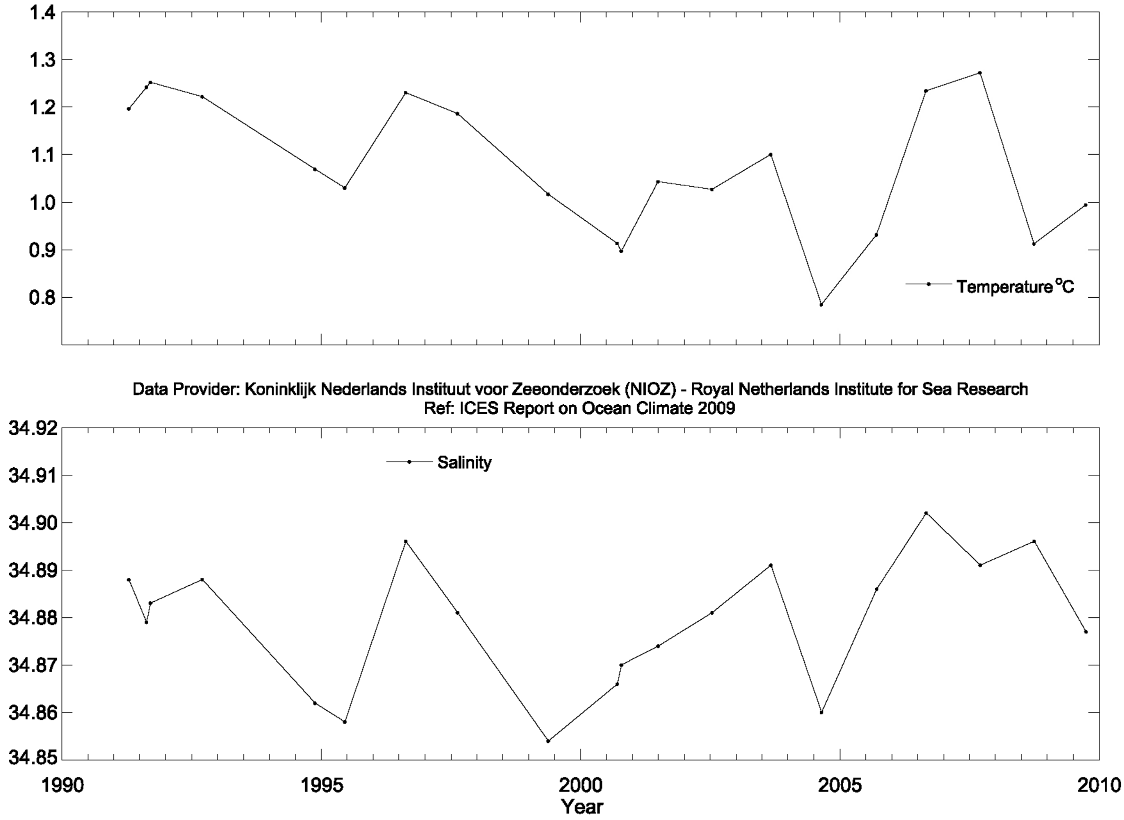


Figure 79.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) in Denmark Strait Overflow Water on the East Greenland Slope.

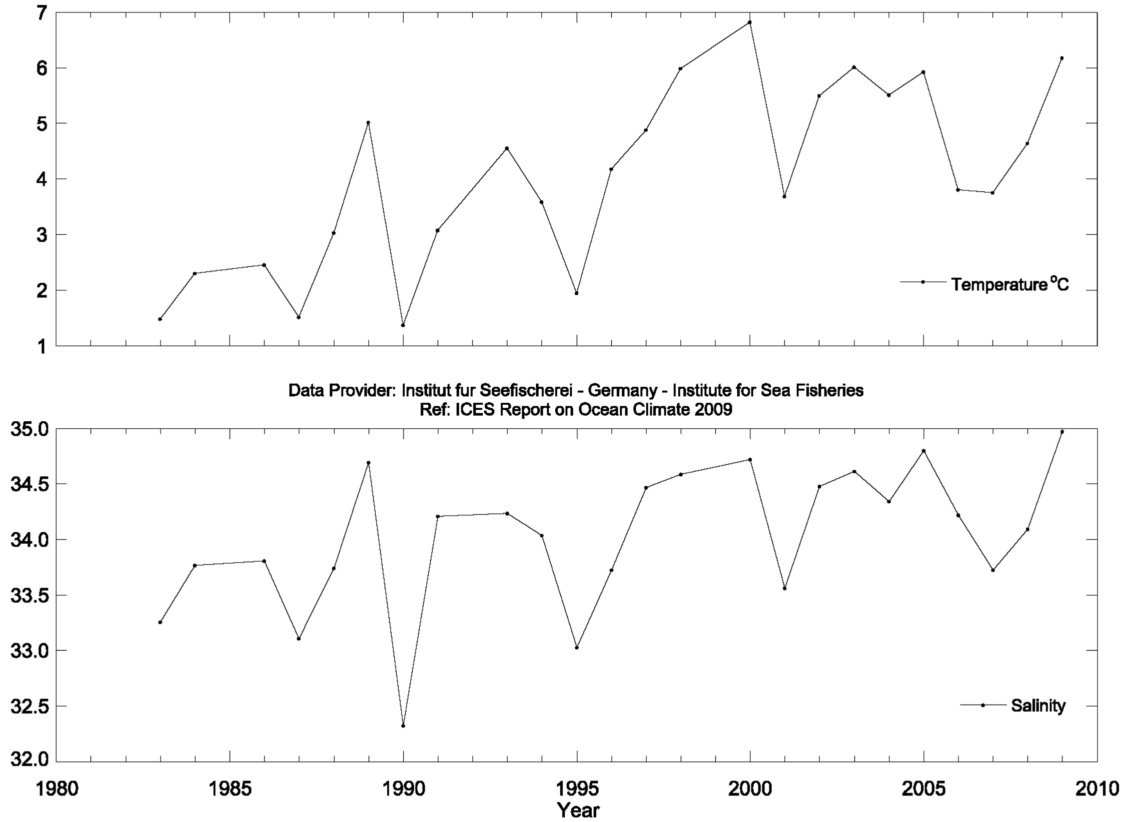


Figure 80.
Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 2000 m at Cape Desolation Station 3 in the West Greenland Current.

5.4 North Atlantic intermediate waters

In the central Irminger Sea (Area 5b), at 1600–2000 dbar, a cold and low-salinity core was observed during the early 1990s. This was the result of the presence of deep Labrador Sea Water (LSW), formed during 1988–1995. Since the summer of 1996, this LSW core has been increasing in temperature and salinity as it mixes with surrounding water masses. The salinity and temperature increases levelled off in 2001–2002, then increased overall until 2008, when they reached the highest values observed since 1991. Although in 2009, the salinity hardly had changed relative to 2008, the temperature of the deep LSW layer had decreased by ca. 0.1°C, likely as a result of the spreading of the cold LSW class, formed in winter 2007/2008 in the Labrador Sea.

In the Rockall Trough (Area 5), the dominant water mass, LSW, is characterized by a minimum in salinity and weak stratification between 1800 and 2000 m. The temperature and salinity of the potential vorticity minimum remain cooler and fresher than the long-term mean. Both temperature and salinity were lower in 2009 than in 2008, but the differences were small and within the variability of the last 15 years, during which time temperature has decreased by approximately 0.01°C year^{-1}, whereas salinity has remained near-constant at 34.931±0.007 since 1992.

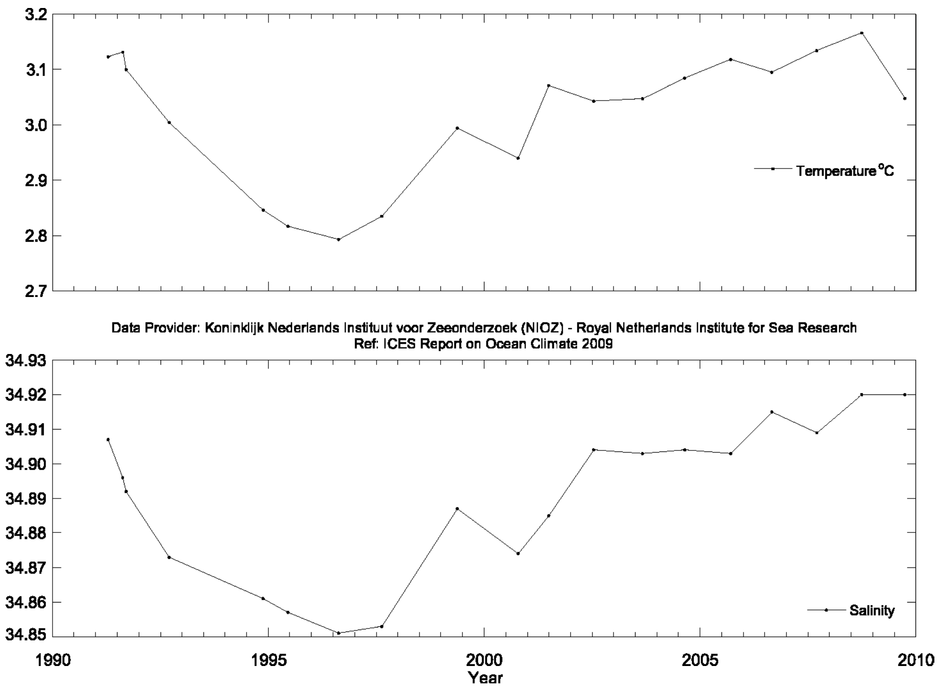


Figure 81.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (averaged over 1600–2000 m).

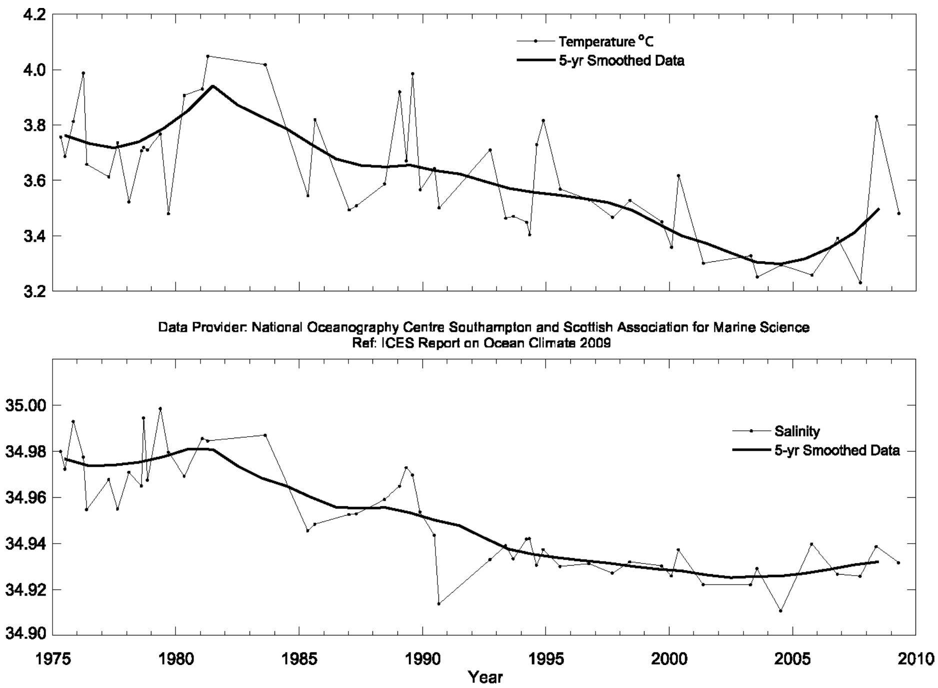


Figure 82.
Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (1800–2000 m).

CONTACT INFORMATION

Area	Figures	Time-series	Contact	Institute
1 West Greenland	14	Nuuk-air temperature	Anna Akimova (ana.akimova@vti.bund.de)	Institut für Seefischerei (Institute for Sea Fisheries), Germany
1 West Greenland	15, 16, 80	Fylla Section and Cape Desolation Section	Anna Akimova (ana.akimova@vti.bund.de)	Institut für Seefischerei (Institute for Sea Fisheries), Germany
2 Northwest Atlantic	17, 18	Sable Island – air temperature, Cabot Strait – sea ice, Misaine Bank	Brian Petrie (PetrieB@mar.dfo-mpo.gc.ca)	Bedford Institute of Oceanography (BIO), Fisheries and Oceans, Canada
2 Northwest Atlantic	19	Emerald Bank	Brian Petrie (PetrieB@mar.dfo-mpo.gc.ca)	Bedford Institute of Oceanography (BIO), Fisheries and Oceans, Canada
2 Northwest Atlantic	20, 21, 22	Sea Ice, Cartwright – air temperature, Station 27 – CIL	Eugene Colbourne (colbourn@dfo-mpo.gc.ca)	Northwest Atlantic Fisheries Centre, Canada
2b Labrador Sea	23, 24	Section AR7W	Igor Yashayaev (Igor.Yashayaev@dfo-mpo.gc.ca)	Bedford Institute of Oceanography (BIO), Fisheries and Oceans Canada
2c Mid-Atlantic Bight	26, 27, 28	Central MAB and Gulf of Maine	Robert Pickart (rpickart@whoi.edu)	Woods Hole Oceanographic Institution, USA
2c Mid-Atlantic Bight	29, 30	Georges Bank	Maureen Taylor (mtaylor@mercury.wh.whoi.edu)	NOAA Fisheries, NEFSC Oceanography Branch, USA
3 Icelandic Waters	31, 32, 33, 34, 35, 76	Air temperatures, Siglunes Stations 2–4, Selvogsbanki Station 5, Langanes Stations 2–6, deep data 1800 m	Hedinn Valdimarsson (hv@hafro.is)	Hafrannsoknastofnunin (Marine Research Institute), Iceland
4 Bay of Biscay	36	San Sebastian – temperature and air temperature	Victor Valencia (vvalencia@pas.azti.es)	AZTI, Aquarium of San Sebastian (SOG) and Igeldo Meteorological Observatory (INM), San Sebastian, Spain
4 Bay of Biscay	37, 38	Santander Station 6 (shelf break)	Alicia Lavin (alicia.lavin@st.ieo.es)	Instituto Español de Oceanografía (IEO, Spanish Institute of Oceanography), Spain
4b NW European continental shelf	39, 40	Western Channel Observatory, Station E1	Tim J. Smyth (tjsm@pml.ac.uk)	Marine Biological Association (MBA) and Plymouth Marine Laboratory (PML), UK
4b NW European continental shelf	41	Malin Head Weather Station	Glenn Nolan (Glenn.Nolan@marine.ie)	Marine Institute and Met Éireann, Ireland
4b NW European continental shelf	42	M3 Marine Weather Buoy	Sheena Fennel (Sheena.Fennell@marine.ie)	Marine Institute and Met Éireann, Ireland
5 Rockall Trough	43, 82	Ellet Line	Toby Sherwin (toby.sherwin@sams.ac.uk) Jane Read (jfr@noc.soton.ac.uk)	Scottish Association for Marine Science (SAMS) and National Oceanography Centre (NOCS), UK
5b Irminger Sea	44, 79, 81	Irminger Sea	H. M. van Aken (aken@nioz.nl)	Koninklijk Nederlands Instituut voor Zeeonderzoek (NIOZ, Royal Netherlands Institute for Sea Research), Netherlands
6 Faroe Bank Channel	45, 46, 47	Faroe Bank Channel Faroe Current, coastal stations	Karin Margretha Larsen (KarinL@frs.fo)	Havstovan, Faroe Marine Research Institute (FAMRI), Faroe Islands
7 Faroe-Shetland Channel	48, 49, 78	Faroe-Shetland Channel	Sarah Hughes (s.hughes@marlab.ac.uk)	Fisheries Research Services (FRS), Aberdeen, UK
8&9 North Sea	50	Modelled North Sea Inflow	Morten Skogen (morten@imr.no)	Institute of Marine Research (IMR), Norway
8&9 North Sea	51	North Sea Utsira A	Solfrid Hjollo (solfrid.hjollo@imr.no)	Institute of Marine Research (IMR), Norway
8&9 North Sea	52	Fair Isle Current Water	Sarah Hughes (s.hughes@marlab.ac.uk)	Fisheries Research Services (FRS), Aberdeen, UK
8&9 North Sea	53, 54	Helgoland Roads – coastal waters – German Bight, North Sea	Karen Wiltshire (kwiltshire@awi-bremerhaven.de)	Alfred-Wegener-Institut / Biologische Anstalt Helgoland (AWI/BAH), Germany
8&9 North Sea	55	Section average – Felixstowe – Rotterdam (52°N)	Stephen Dye (stephen.dye@cefas.co.uk)	Centre for Environment Fisheries and Aquaculture Science (CEFAS), UK
8&9 North Sea	56	Sea surface temperature – North Sea average	Peter Loewe (peter.loewe@bsh.de)	Bundesamt für Seeschifffahrt und Hydrographie, Hamburg, Germany
9b Baltic Sea	57, 62	Baltic Proper, east of Gotland, and observed ice extent	Karin Borenas (karin.borenas@smhi.se)	Swedish Meteorological and Hydrological Institute (SMHI), Sweden
9b Baltic Sea	59, 60, 61	Stations LL7, BO3 and SR5	Pekka Alenius (pekka.alenius@fimr.fi)	Finnish Institute of Marine Research (FIMR), Finland
10 Norwegian Sea	63, 64, 65	Svinøy, Gimsøy, and Sørkapp Sections	Kjell Arne Mork (kjell.arne.mork@imr.no)	Institute of Marine Research (IMR), Norway
10 Norwegian Sea	67, 77	Ocean Weather Station "M"	Svein Østerhus (Svein.Osterhus@gfi.uib.no)	Geophysical Institute, University of Bergen, Norway
11 Barents Sea	68	Fugløya – Bear Island Section, western Barents Sea (Atlantic Inflow)	Randi Ingvaldsen (randi.ingvaldsen@imr.no)	Institute of Marine Research (IMR), Norway
11 Barents Sea	69	Kola Section, eastern Barents Sea	Oleg V. Titov (titov@pinro.ru)	Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Russia
12 Greenland Sea and Fram Strait	70	Greenland Sea Section west of Spitsbergen, 76.5°N	Waldemar Walczowski (walczows@iopan.gda.pl)	Institute of Oceanology, Polish Academy of Sciences (IOPAS), Poland
12 Greenland Sea and Fram Strait	71, 75	Greenland Sea Section, 75°N	G. Budeus (Gereon.Budeus@awi.de)	Alfred Wegener Institute for Polar and Marine Research (AWI), Germany
12 Greenland Sea and Fram Strait	72	Fram Strait Section	A. Beszczynska-Möller (abeszczynska@awi-bremerhaven.de)	Alfred Wegener Institute for Polar and Marine Research (AWI), Germany
12 Greenland Sea and Fram Strait	74	Convection depths in the Greenland Sea	G. Budeus (Gereon.Budeus@awi.de)	Alfred Wegener Institute for Polar and Marine Research (AWI), Germany

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer